Reference Government Contract: N00014-93-C-0020
Reference SC: 05-2446-33

Single Crystal Terfenol-D Development

Final Report

28 July 1994

Submitted To:

Office of Naval Research
Ballston Tower One
800 North Quincy Street
Arlington VA 22217-5660

Technical Points of Contact:
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Submitted By:

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Technical: P. David Baird (801) 486-7481 x311

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Acknowledgement

EDO Undersea Warfare Division wishes to recognize the technical contributions of Art Clark and Joseph Tetter both of the Naval Surface Weapons Center, Silver Spring, Md. These individuals provided comments and testing which were instrumental in the execution of this program. There advice and experience was given freely in an environment of genuine cooperation between Government and Industry.

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Appendix - Engineering Design, Analysis and Drawings

1.0 Introduction

This report will provide a review of both existing and newly attempted methods for processing Terfenol-D. This review will describe each process and highlight both benefits and drawbacks of each method. The commonly used method of manufacturing Terfenol-D today is the referred to as the Float Zone Growth Method. EDO proposed to develop the following two alternate manufacturing methods the Traveling Heater Method and the Dash Method. The Traveling Heater Method appeared to provide the greatest probability of success and was therefor the focal point at the onset of the process development. Due the short duration of the contract, approximately 3-4 months, little effort was initiated on the DASH Method.

2.0 Program Objective

The objective of this program has been to develop <u>low cost</u> processes that would produce <u>single, non dendritic, and non-rotationally twinned crystals</u> of the rare earth magnetostrictive material Terfenol-D (RFe_2).

The performance benefit of the development of the stated material would be a higher magnetostrictive strain-field constant, as illustrated in Figure 2-1, which in turn would result in lower DC bias fields and more compact bias coils/bias magnets. The saturation strain is expected to be similar to existing Terfenol-D materials.

A second benefit would be derived in cost. High raw material costs, labor intensive manufacturing techniques and low manufacturing yields results in very high end product costs. The use of low purity materials (ie lower cost) combined with automated processes would result in a substantial reduction of costs on the order of 5 to 1.

3.0 Fe Tbx Dy(1-x) Compounding

The raw materials (Fe platlets, Dy and Tb chunks) are compounded using an arc melter in an non-reactive argon environment. The uncompounded materials are set on a <u>water cooled</u> copper hearth. This prevents the materials from melting onto and <u>reacting</u> with the copper surface. The high current, low voltage arc melter provides the heat to melt and compound the materials. The slab of material is flipped over and repeatedly melted. Typically the Tb and Dy are compounded first.

The stoichiometry of this mixture can be affected during this compounding process. Loss of material can occur through material ejection (slab cracking) or through vaporization. In Float Zone Growth all of the materials remain with the final rod (i.e. no transport of excess material or contaminants to an end). A change in stoichiometry can dramatically effect the performance of the final product.

An improved method of compounding larger volumes of material is detailed in Appendix A.4. but was not implemented during the program.

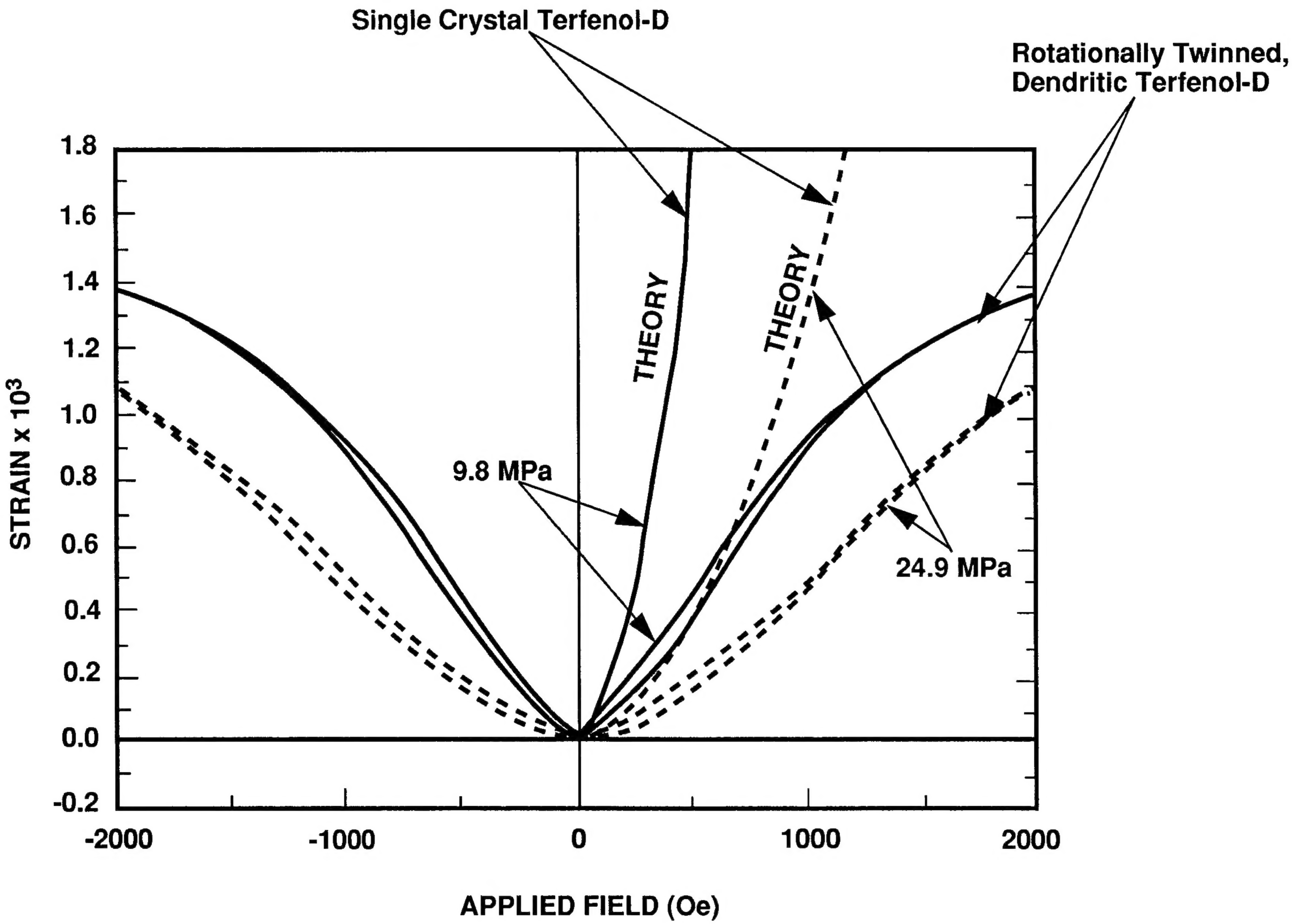


Figure 2-1, Magnetostrictive Strain-Field Curve

4.0 Fe Tbx Dy(1-x) Casting

The compounded material is placed in a quartz crucible and melted using an RF induction heater in an non-reactive argon atmosphere. The molten material is then either poured into or drawn up into a quartz tube.

The pouring technique utilizes a quartz crucible with a hole in its base. A thermocouple rod seals the hole in the base of the crucible until the desired pouring time. Many rods can be cast in a short period of time using this technique.

The second technique applies a partial vaccum to the end of the quartz tube. Pressurized argon on the surface of the molten compounded material forces it up into the tube.

The major problem with either technique is bracking of the quartz tube during casting. The tube must be preheated prior to filling. A resistance heater placed around a tube(s) will raise the temperature to approximately 800°C.

5.0 Float Zone Growth Method (FZGM)

This process requires the use of an off-stoichiometric compounded material, as illustrated in Figure 5-1. RFe_2 is the desired magnetostrictive end product. This process generates plate like dendritic, edged defined, rotationally twinned crystals. Between the rotational twins is a backbone of rare earth rich material. The typical float zone growth process steps are as follows:

An RF induction heater, surrounding the rare earth-iron rod, creates a molten zone in the sample rod (compounded and cast material). As the heater or rod is translated along the molten zone moves with it. The rate of translation is dependent upon the induction heating effectiveness. Input power flucuations (5% common) dramatically effect the temperature and therefor the rate of travel. If the molten zone is not wide enough, it results in a freeze out in the center of the rod. This results in a core of unoriented material and a useless rod. Unfortunately there is no means of automated temperature control of the rare earth rod. Visual control of temperature is difficult because the quartz tube fogs.

EAD has implemented power stabilization circuit for the RF induction heater. This has resulted in a reduction of process labor. This process still requires constant monitoring and subtle adjustments in position and temperature in order to yield high quality materials. Typical process rates are approximately 18 inches per hour.

Prior to contract award, EAD attempted to grow true single crystals by slowing down the baseline float zone process. The result was a rod that tried to grow single but in the wrong direction. The magnetostrictive strain field performance of these rods were much lower.

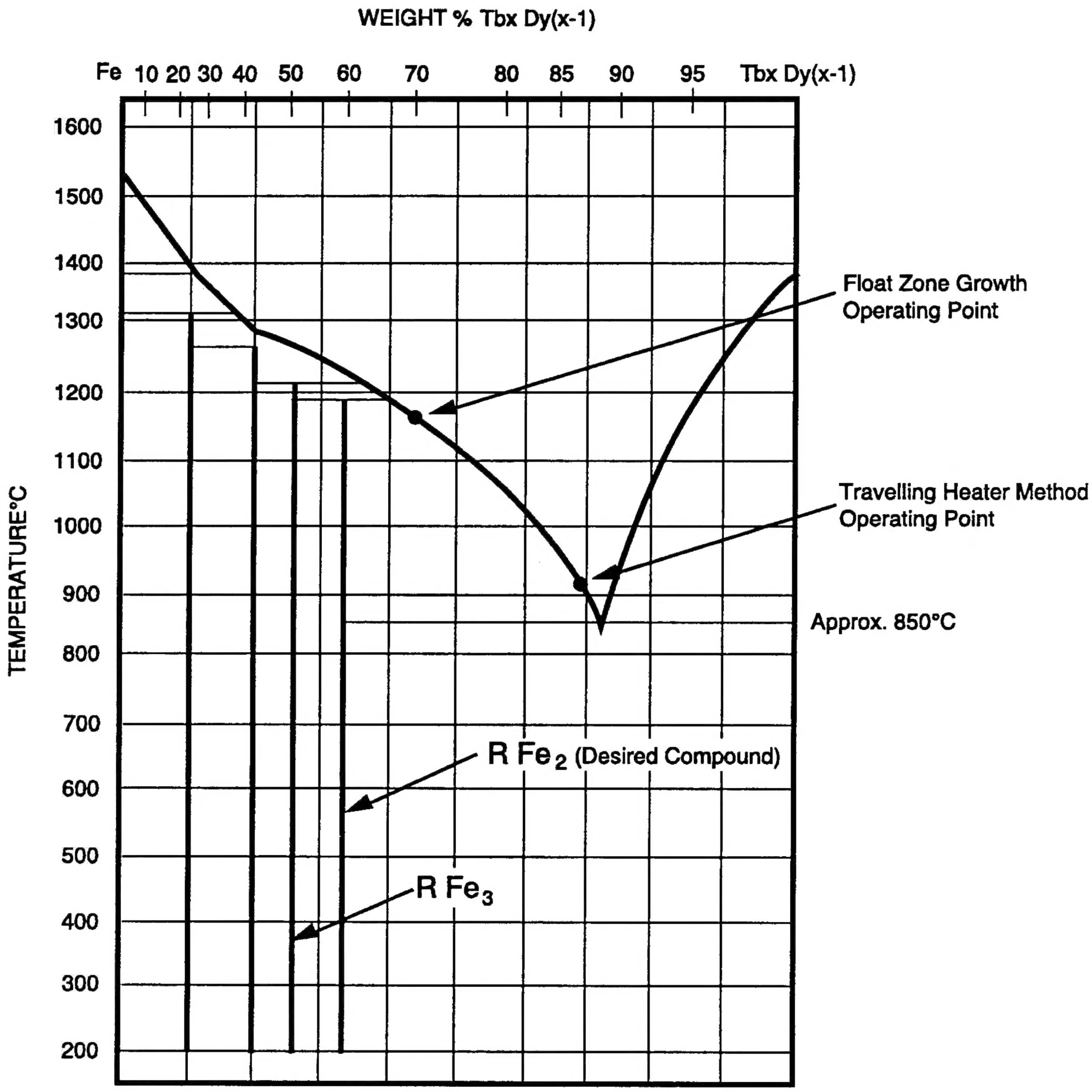


Figure 5-1, $Tb_x Dy_{(1-x)}$ Fe Phase Diagram

6.0 Traveling Heater Method (THM)

The traveling heater method is a zone refining process. This method has been used successfully to grow high quality Cadmium Telluride and Gallium Arsenide crystals. The process as is pertains to Terfenol is illustrated in Figure 6-1. There are three rare earth compounds associated with crystal growth process: (1) Terfenol-D seed, (2) eutectic solvent, and (3) a Terfenol-D feed rod. The furnace or the process sample may be translated in this process. The Terfenol-D seed provides crystal growth surface. This seed would eventually be refined during processing into a "single crystal seed". The eutectic solvent provides a means of lower temperature transport of raw materials to the seed as well as filters out impurties. The feed rod is provides the raw material for crystal growth.

Rare earth compounds have a great affinity for oxygen. Raw materials, compounding, casting and final processing steps all introduce oxides (or other impurities) into the material. These oxides would contaminate the material and one would expect an impact upon magnetostrictive performance. It is therefor desirable to purge the material of oxides. THM does just that. The problem of rare earth oxides contamination is eliminated in THM by virtue of the oxides lower density relative to the eutectic solvent. The traveling furnace moves upwared carrying the solvent and oxides along with it. The eutectic solvent of choice is $Tb_{20.2}Dy_{48.3}Fe_{31.4}$ wt %.

The introduction of new oxides during the final THM processing is expected to be greatly reduced. Rare earth reaction with the quartz crucible are very low due to the lower zone refining temperature of approximately 900°C (ref. Figure 5-1). The reaction rate decreases by a factor of 10 for each 50°C drop in temperature. The THM reaction rate would be 10^{-5} of the FZGM.

This process requires very precise control over temperature and translation of the eutectic solvent. The lower process temperatures permit the use of a resistance heater furnace which can easily be <u>automatically</u> controlled to ±0.2°C. The furnace can be translated automatically as well resulting in elimination of costly labor.

The negative side of this process is its relatively slow speed. The melting of the feed rod and diffusion of the materials through the eutectic solvent are slow. EDO estimates a process speed of .1 to 2 mm per hour. When balancing the requirement for slower process speed against the cost benefits of (1) greatly reduced labor demands, (2) reduced energy consumption, and (3) reduced material costs, the speed becomes less of an issue.

The engineering design and sketches of the hardware associated with the THM process and alternate processes (Dash and Czochralski) undertaken in this contract are provided in the Appendix. Materials and equipment were purchased under contract to support primarily the THM process development.

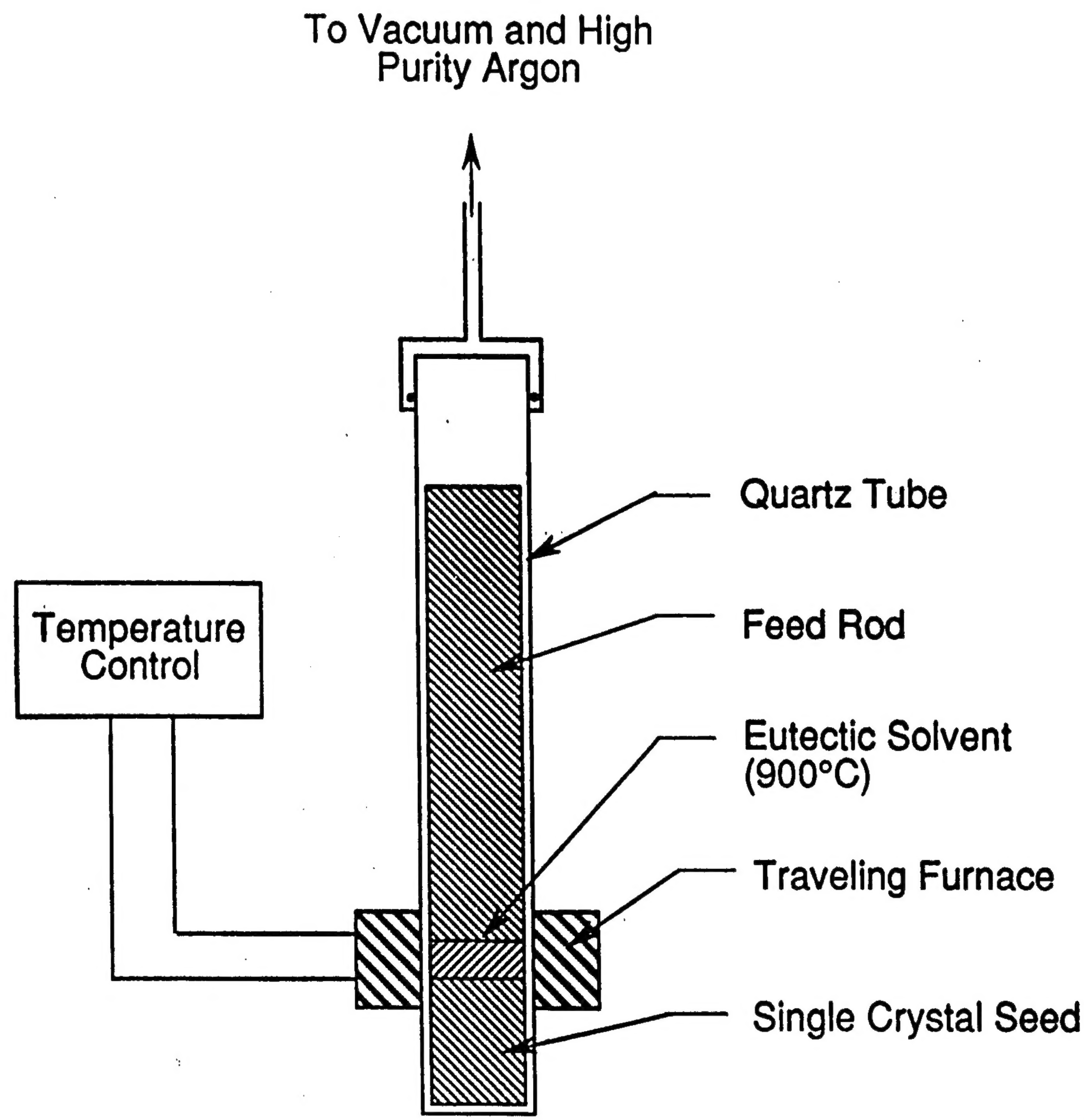


Figure 6-1 Traveling Heater Method Illustration

7.0 THM Crystal Growth Experiment and Results

In advance of the procurement of the engineered crystal growing equipment, EDO attempted to grow single crystal Terfenol-D utilizing existing laboratory equipment. The composition of the feed and seed rods should be stoichiometrically balanced RFe_2. Crystal growth with off stoichiometric compositions would eventually change the eutectic melting temperature. Since the planned process length was short (~4-5 mm), float zone refined Terfenol-D material was substituted The feed and seed rod compositions were $Tb_{16.9}Dy_{43.3}Fe_{39.8}$ wt % while the eutectic was $Tb_{20.2}Dy_{48.3}Fe_{31.4}$ wt %. The resistance heater was not available at the time of experiment and so an existing induction heater was utilized. Constant attention was required in order attempt to maintain a uniform zone temperature. A slow and smooth motorized translation system was not available and therefore required the operator to periodically make large (.3 mm) translational steps of the sample. The process test required approximately 12 hours to complete. The rate of movement was 0.5 mm per hour resulting in an net translation of 6 mm. When the zone refined region was removed from the feed rod and fractured, there appeared to be 3 large crystals and 5 small crystals. A photograph of the fractured THM sample is illustrated Figure 7-1. Analysis of the sample using X-ray florescence energy dispersion technique at two locations are provided in Figures 7-2 and 7-3. The measurements indicated that the composition was 39.48% Fe, 19.63% Tb, 40.89% Dy and 37.40% Fe, 17.27% Tb, 45.32% Dy for the respective samples. The $Dy_xTb_{(1-x)}$ component of RFe_2 is expected to be 57% but is actually approximately 60-63% or rare earth rich.

Joseph Tetter of NSWC/Silver Spring requested use of crystal sample for further evaluation. The samples were to be prepared at NSWC prior to testing in England. The sample would be evaluated using two techniques: (1) differential interference contrast and (2) Berg-Barrett. The differential interference technique uses coherent visible light over a range of wavelengths. When actived with a magnetic field a rotationally twinned surface looks different than single crystal surface. The Berg-Barrett technique utilizes the scattering of low energy X-rays incident at a 90° angle re the normal to the crystal surface. Again, when actived with a magnetic field, a rotationally twinned surface scatters the X-rays differently than single crystal surfaces.

Joseph Tetter did identify 8 single crystals within the sample provided. The magnetic measurements using the stated techniques resulted in some odd results (no detailed results were disclosed to EDO). Tetter performed his own chemical analysis yield the following compound $Tb_{0.9}Dy_{31.6}Fe_{57.5}$ wt % or what Tetter believed to be RFe_3. NSWC has retained the sample.

The rate of diffusion of Tb and Dy through the eutectic solvent would be different. Dy would diffuse more rapidly. If the zone was translated to quickly or erratically than it is conceivable that an imbalance in Tb and Dy diffusion could occur, resulting in primarily a DyFe product.

The discrepancies between the EDO and NSWC measurements of composition have remained unresolved.

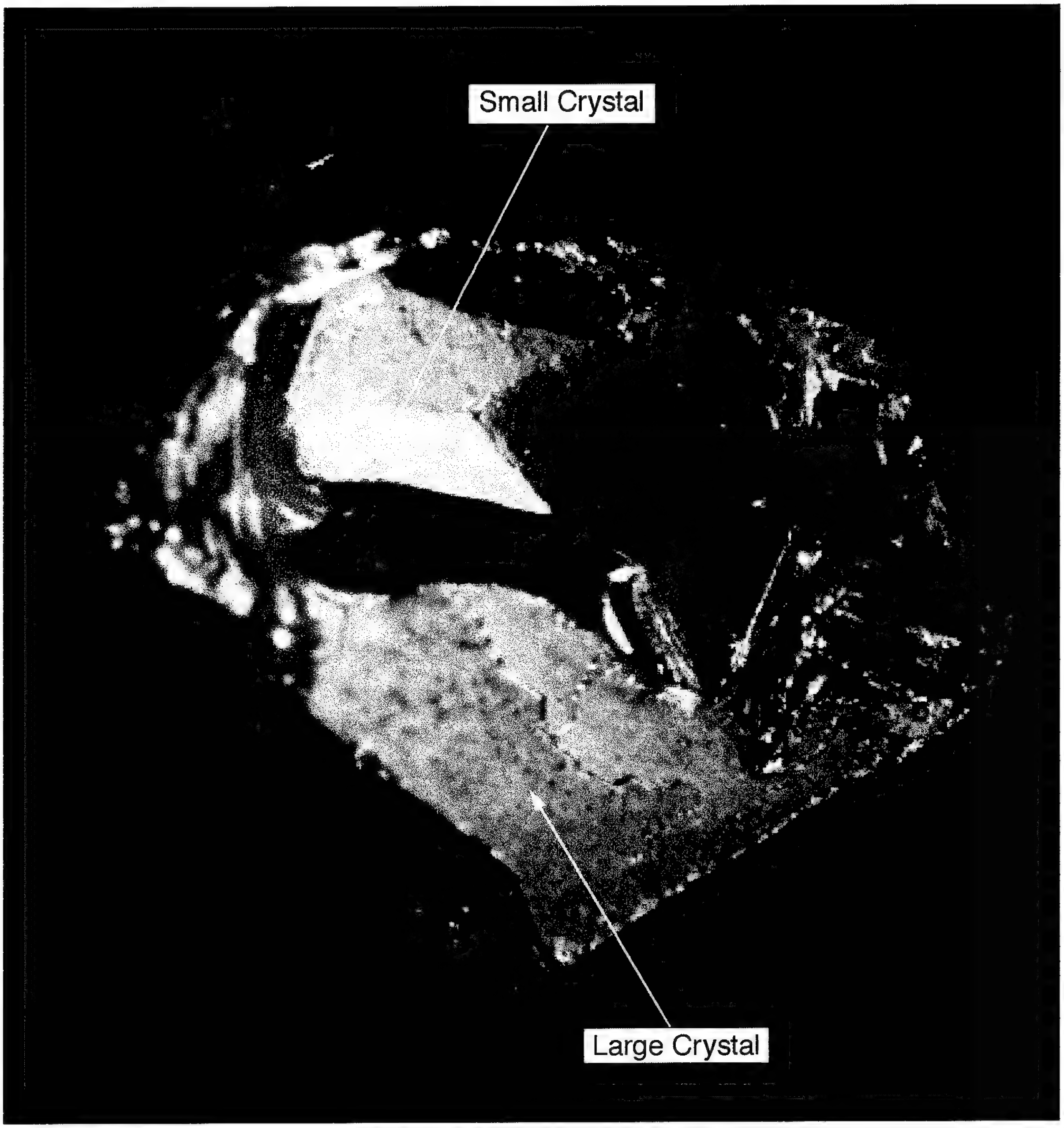


Figure 7-1, THM Terfenol - D Crystal Sample

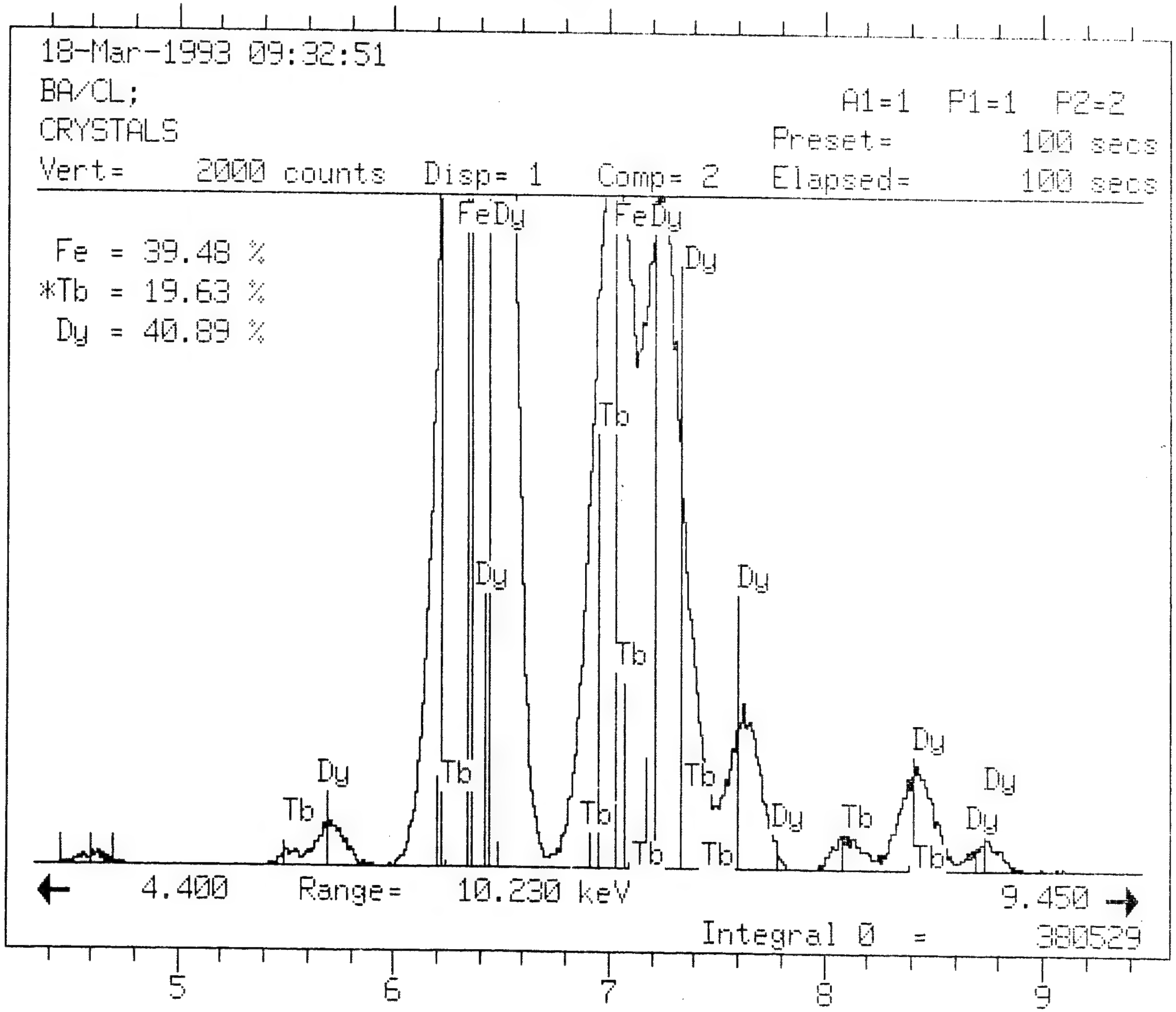


Figure 7-2 THM Terfenol-D Crystal Chemical Analysis, Sample Point A

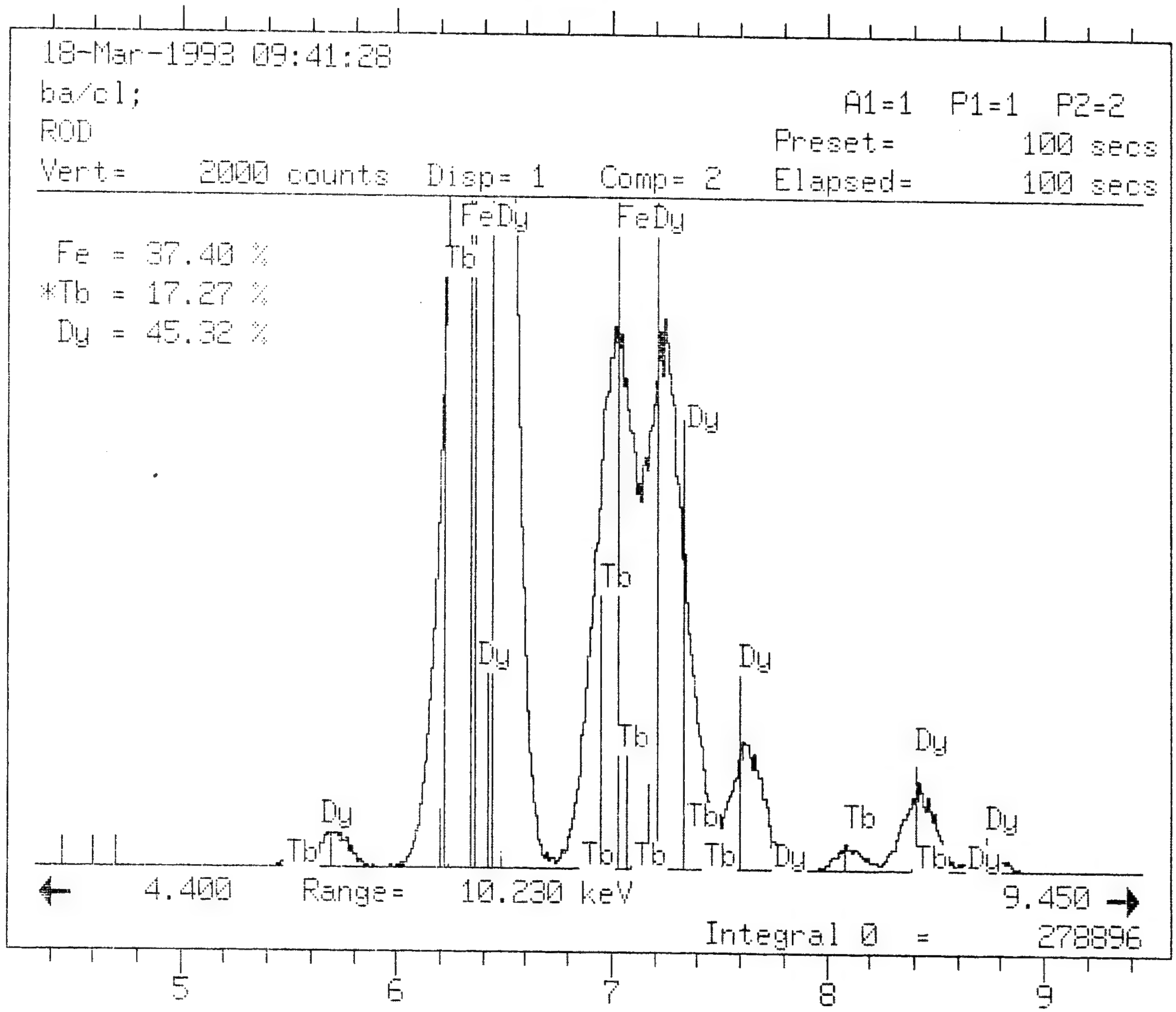


Figure 7-3 THM Terfenol-D Crystal Chemical Analysis, Sample Point B

Appendix

Engineering Design, Analysis and Drawings

A.1 Vacuum System

Because oxides are a difficult to control contaminant in the Terfenol crystal growing systems, many operations must be carried out under vacuum. Figure A-1 shows the layout of the planned vacuum system for the Terfenol laboratory. This system was designed to make use of a single rough pump and cryopump for all the laboratory's needs. Tubing runs have been kept as short as possible, and there are numerous valves that are used to seal off portions of the system when they are unused, minimizing the volume to be evacuated. Figures A-2A and A-2B are a parts list with cost estimates for this vacuum system.

A.2 Traveling Heater Method

Figure A-3 is conceptual layout drawing for the traveling heater method apparatus. Once a Terfenol rod is cast inside a small diameter quartz tube, it is suspended from a pulley by a cable. The casting is slowly lowered down through the central diameter of a silicon carbide heating element. A small segment of the heating element, approximately 1 inch long, is surrounded by an aluminum silicate insulating ring. This causes a local area of higher temperature inside the heating element that becomes the melt zone of the cast Terfenol rod. Crystalline Terfenol forms in the base of the melt zone. The melt zone travels up the rod, until a large segment of the rod has formed the hopefully single crystal Terfenol.

The rod must be lowered through the melt zone slowly enough that the crystals have time to form. Experience with other growth apparati of this type suggests that the proper rate will be in the vicinity of 4 mils/hr to 40 mils/hr. Such slow, controlled motion requires a drive motor with a very large reduction gearing. Consistent crystal growth also requires very smooth motion. The allowable variation in velocity is unknown, but ±1% was used as a design goal.

A platinum-rhodium thermocouple is required to withstand the high temperatures in the heating zone (approximately 1350°C). It is positioned inside the heating element and used as a feedback sensor to the temperature controller, controller, an SCR.

Figure A-4 is an apparatus parts list for the Traveling Heater Method, with estimated costs and targeted acquisition dates.

A.3 DASH and Czochralski Methods

Because the DASH method of crystal growth is a variation of the well known Czochralski method, there can be much commonality to the apparati required for both methods. This was considered in our apparatus design. Both methods were to be carried out inside the same water cooled pressure/vacuum chamber. The heating elements and some associated apparati would be different for each, as described below.

A.3.1 DASH Method Apparatus

Figure A-5 is a conceptual layout drawing for the DASH Method. In this method the single crystal is pulled slowly upward out of the melted surface of a cast boule of raw Terfenol materials.

The boule's surface is heated by an induction heater with a concentrator coil. The purpose of the concentrator coil is to confine the induction heating to a small area at the center of the boule. Figure A-6A is a concept sketch of the concentrator coil, showing the coil in relation to the melted surface of the boule. Figures A-6B and A-6C show two experimental coil designs. The concentrator coil is cooled by water flowing through the conductor coils that would be brazed to its surface. Figures A-7A and A-7B are design calculations that were used to estimate the required water flow rates to adequately cool the concentrator coil. Figure A-8 is a feed-through design for transmitting power and cooling water to the concentrator coil.

Additional details can be noticed in the overall concept drawing, Figure A-5.

A platinum-rhodium thermocouple is positioned as closely as possible to the melted surface for temperature measurements (approximately 1350°C).

Motor #1 drive the moving crosshead that slowly pulls the crystal upward out of the melt at a rate of .02 to .5 inches per hour. Motors #2 and #3 rotate the boule and sample in opposite directions at rates of somewhere between 25 and 40 RPM. The hand crank and roller screw are used to raise the boule to compensate for its loss of volume as material is pulled from the surface to form the crystal. The hand crank was low cost alternative to another motor drive system. It was planned to have the hand crank replaced by another motor drive after proof-of-concept experiments had been performed.

A.3.2 Czochralski Method Apparatus

The Czochralski method has some similarity to the DASH method, but instead of melting the surface of a boule by induction heating, a crucible of amorphous Terfenol is melted by a resistance heating furnace. Because of the similarities, the same water-cooled vacuum/pressure vessel would be used for both methods. Both methods take place inside a pressure vessel that has first been evacuated to about 10-7 Torr, then backfilled to a positive 20 psi with argon gas. These precautions are to prevent contamination of the raw material or crystal with oxides. Figures A-9A and A-9B are preliminary working drawings for the chamber details. The pressure vessel would be cooled by water flowing through channels in the walls, base, and cap. It was planned to use shrink-fit construction to form these water channels in the walls of the vessel. Figures A-10A through A-10C are design calculations for this type of construction. Figures A-11A through A-11D are computerized calculation results that were used in making design trade-offs.

Figures A-9A and A-9B show the Czochralski method, with a crucible inside the heating furnace. The furnace is surrounded by a heat shield made of three layers of 30 mil thick tantalum sheets. Figure A-12 is a pedestal to position the crucible.

In the initial concept for the Czochralski method, a ring a five silicon carbide heating elements surrounding the crucible was considered. Figures A-13A and A-13B were created during this effort. This approach was later abandoned in favor of the molybdenum wire required 1400°C and provided significant cost savings over the silicon carbide elements or molybdenum-disilicide wire elements.

Figures A-14A and A-14B are a combined parts list for the DASH and Czochralski methods with estimated costs and target acquisition dates.

A.4 Compounding and Casting Apparatus

Regardless of the method of crystal growth, it was considered important to control oxide contamination in the raw material as it was mixed and cast. A Vacuum chamber for mixing raw materials was planned. Figures A-15A and A-15B show a pressure cap for this chamber. During mixing, it was planned to thorough mix the molten Terfenol constituents by using an yttria stirring paddle. The handle of this paddle would protrude through the central hole of the pressure cap. Figure A-16 is a drawing of the stirring paddle, and Figures A-17A and A-17B depict modifications of a standard pressure fitting to allow passage of the paddle's handle.

Figure A-18 is a fixture used to hold 6 quartz tubes inside the vacuum chamber (a larger diameter quartz tube) so that all six could be cast full of raw Terfenol during one casting session.

A.5 Strain-Field Testing Apparatus

Figures A-19 through A-26 are drawings and design calculations used in developing a test apparatus for low frequency testing of Terfenol rods.

Figure A-19 is an estimate of the lower limit of strain resolution achievable using strain gage techniques. The strain gage method was not used, however, due to concerns over how the strong magnetic fields surrounding the Terfenol rod would affect the strain gage signals.

Another test method that was tried, but later abandoned, was to use a long lever arm to amplify the strain of the rod under test. Efforts were made to produce the lightest, **stiffest** lever arm possible so the resonant frequency of the apparatus would be significantly higher than the frequencies used in testing. Figure A-20 is a calculation of the area moment of inertia of an lever arm having the cross section of an I-beam. Figure 21 is a calculation of the resonant frequency of the same beam, and the amount of static deflection to under its own weight. Figures A-22A and A-22B are computer aided

calculations used in making design trade-off studies, and a graphical representation of resonant frequency vs. length for a candidate design. Figure A-23 is a sketch of the I-beam, made of epoxy/graphite composite, that was built for use in the apparatus.

The strain capability of a Terfenol rod varies with the amount of longitudinal stress it is under. The test fixture had provisions for supplying a controlled prestress to the rod from a pneumatically driven piston. The load was applied to the rod ends through hemispherical load-button-and-socket joints that would transmit longitudinal force without transmitting bending moments to the rod. This concept is illustrated in Figure A-24. Stress calculations for this joint are shown in Figure A-25, and the load button and socket are shown as drawings 6784RD1 and 6784RD2.

Drawings 6784RD3 through 6784RD19 are the main portions of the test apparatus frame and miscellaneous fittings used in conjunction with it. Figure A-26 is an apparatus parts list.

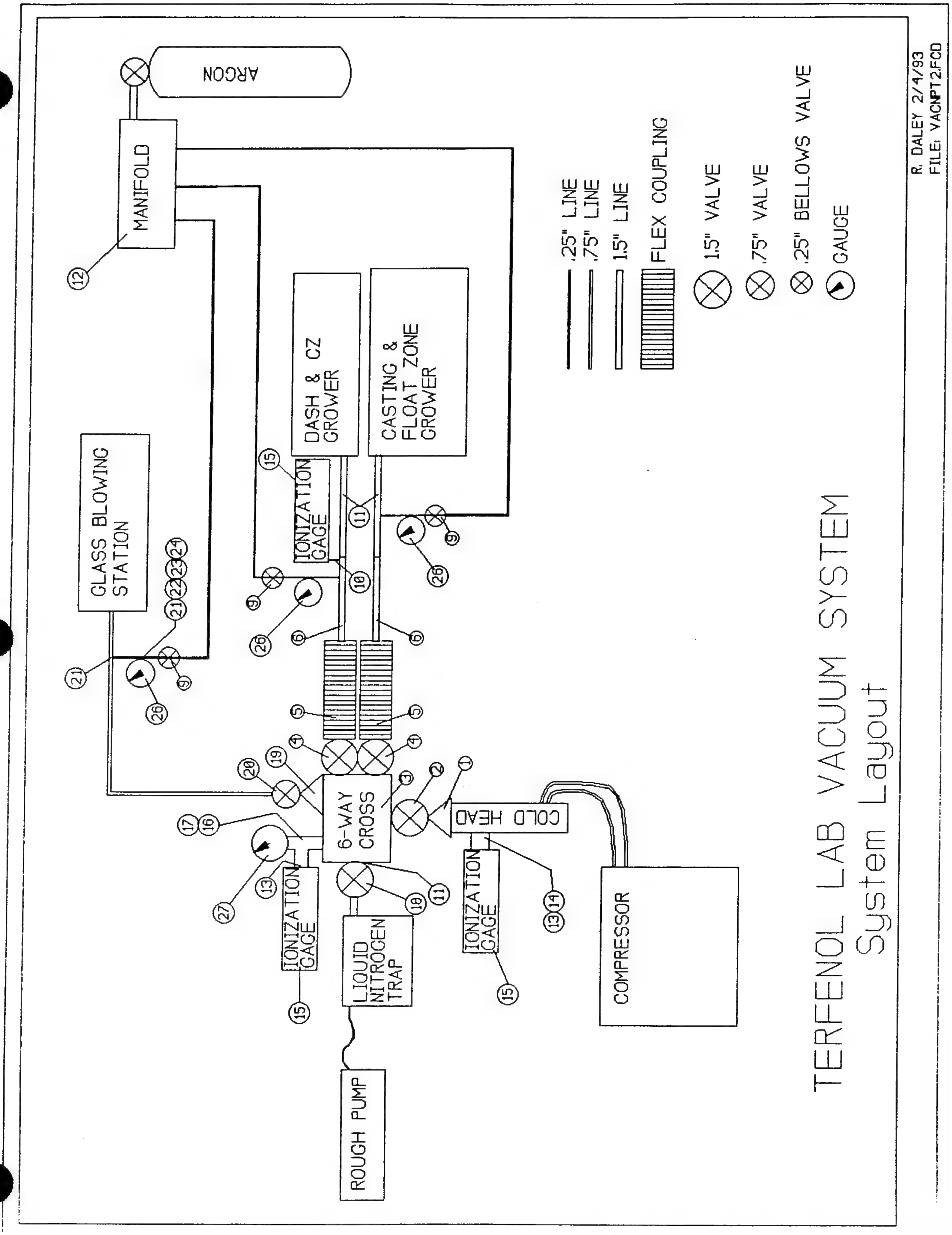

TERFENOL LAB VACUUM SYSTEM
System Layout
ARGON
MANIFOLD
GLASS BLOWING STATION
DASH & CZ GROWER
CASTING & FLOAT ZONE GROWER
IONIZATION GAGE
IONIZATION GAGE
IONIZATION GAGE
6-WAY CROSS
COLD HEAD
COMPRESSOR
LIQUID NITROGEN TRAP
ROUGH PUMP
.25" LINE
.75" LINE
1.5" LINE
FLEX COUPLING
1.5" VALVE
.75" VALVE
.25" BELLOWS VALVE
GAUGE
R. DALEY 2/4/93
FILE: VACNPT2.FCD

FIGURE A-1

TERFENOL LAB VACUUM SYSTEM PARTS LIST
2/4/92
R. Daley

BALLOON NO.	MFG's PN	DESCRIPTION	NUMBER IN SYSTEM	NUMBER REQUIRED TO PURCHASE	PRICE EA.	VENDOR	EXTENDED COST
1	150016	6 to 2.75 Del-Seal Flange Adapter	1	1	95.00	MDC	95.00
2	312029	Right Angle Valve with 2.75 Del-Seal Flanges	1	1	375.00	MDC	375.00
3	407002	6-Way Cross: 2.75 Del-Seal Flanges	1	1	240.00	MDC	240.00
4	322018	Valves; 2.75 Del-Seal Flanges	2	2	365.00	MDC	730.00
5	400003	Bellows; 2.75 Del-Seal Flange	2	2	100.00	MDC	200.00
6	402002	Nipple; 5" Long 2.75 Del-Seal Flanges	2	2	55.00	MDC	110.00
7	SS-4-TSW-3	1/4" Socket Weld Union Tee	2	2		SLV	
8	SS-4-TSW-7-4	Tube Socket Weld Female Connector 1/4" Tube to 1/4" NPT	2	2		SLV	
9	SS4BK	Bellows Valve	3	0		-	
10	410008	3/4" Stainless Steel Quick Disconnect	1	1	35.00	MDC	35.00
11	730003	2.75 Del-Seal to NW40 Quick Flange Adapter	3	3	65.00	MDC	195.00
12	SS-400-4	1/4" Tube Union Cross	1	1		SLV	
13	412008	2.75 Del-Seal Flange to 3/4" Quick Disconnect Adapter	2	2	80.00	MDC	160.00
14	150001	2.75 Del-Seal Flange to 1.33 Reducer	1	1	50.00	MDC	50.00
15	432022	Ionization Gauge	3	3	80.00	MDC	240.00
16	404002	2.75 Del-Seal Flange Tee	1	1	83.00	MDC	83.00
17	130008	2.75 Del-Seal Flange Blank: Have Vendor Tap Center for 1/8" NPT Thread	1	1	20.00+	MDC	20.00+
18		Valve; NW40 Flange Both Sides	1	0	0	-	0

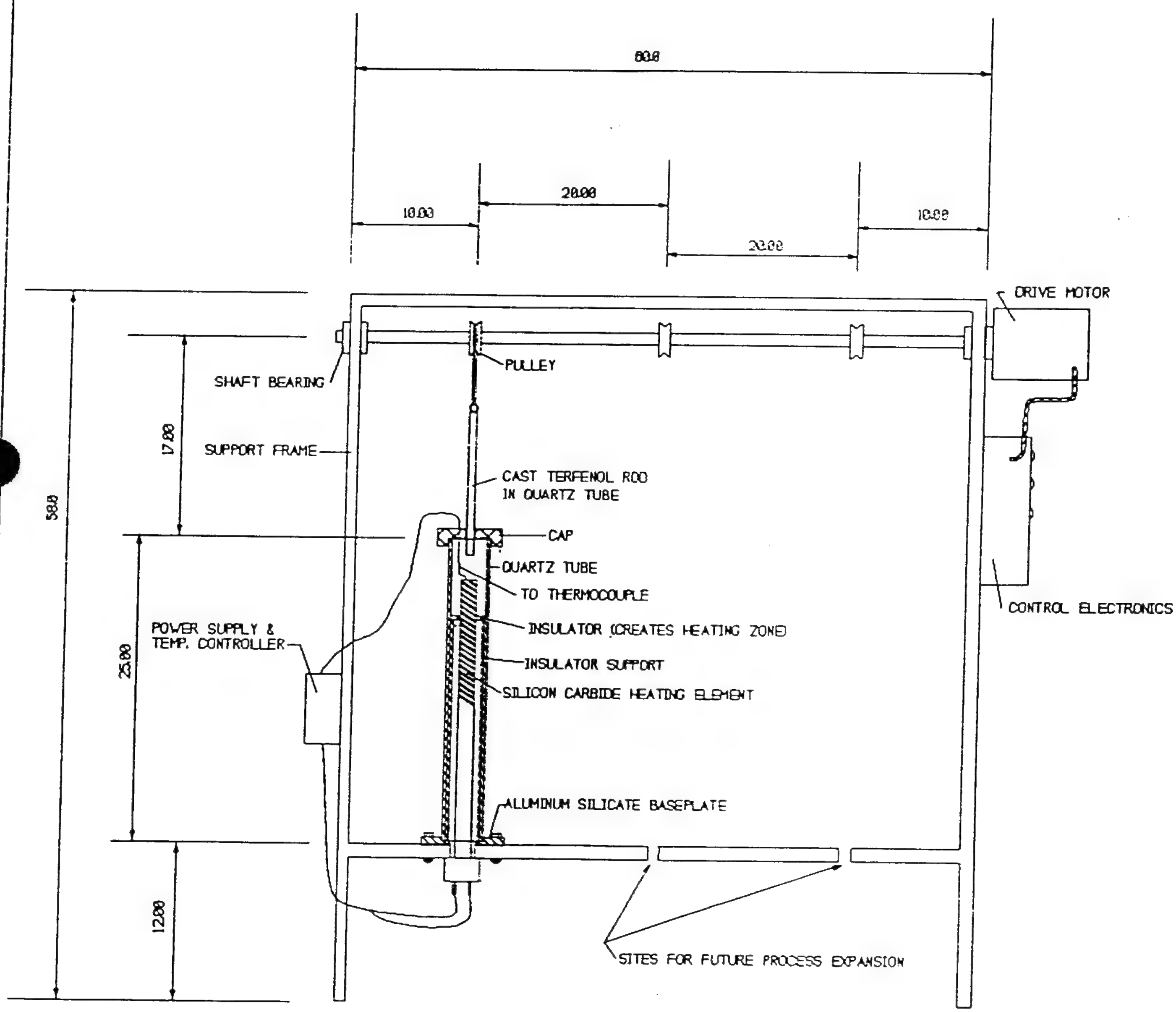
FIGURE A-2A

19	110011	2.75 Del-Seal Flange to 3/4" Weldable Flange Reducer	1	1	14.00	MDC	14.00
20	SS-8BK-TW	Bellows Valve; 3/4" Butt Weld	1	1		SLV	
21	SS-12-TSW-3	Tube Socket Weld Union Tee	2	2		SLV	
22	SS-12-MPW-A-8TSW	3/4" Pipe to 1/2" Tube Weld Adapter	1	1		SLV	
23	SS-4-TSW-7-4	Tube Socket Weld to 1/4" NPT	1	1		SLV	
24	SS-12-MTW-A-8TSW	3/4" to 1/2" Tube Weld Adapter	1	1		SLV	
25	SS-8-MTW-A-4TSW	1/2" to 1/4" Tube Weld Adapter	1	1		SLV	
26	111.10	Pressure Gauge 2.5" Dial 30" Hg-0-30 psi 1/4" NPT at Base	3	3	10.24	JMC	30.72
27		Thermocouple Gauge	1	0	0	-	0

MDC= MDC High Vacuum Components, Hayward, Ca., (415)-887-6100
SLV= Salt Lake Valve, SLC, Ut., 266-3560
JMC= JMC instruments, SLC, Ut., 972-8920

FIGURE A-2B

TRAVELLING HEATER METHOD
Apparatus Concept



FILE THMCNCPT.FCD

FIGURE A-3

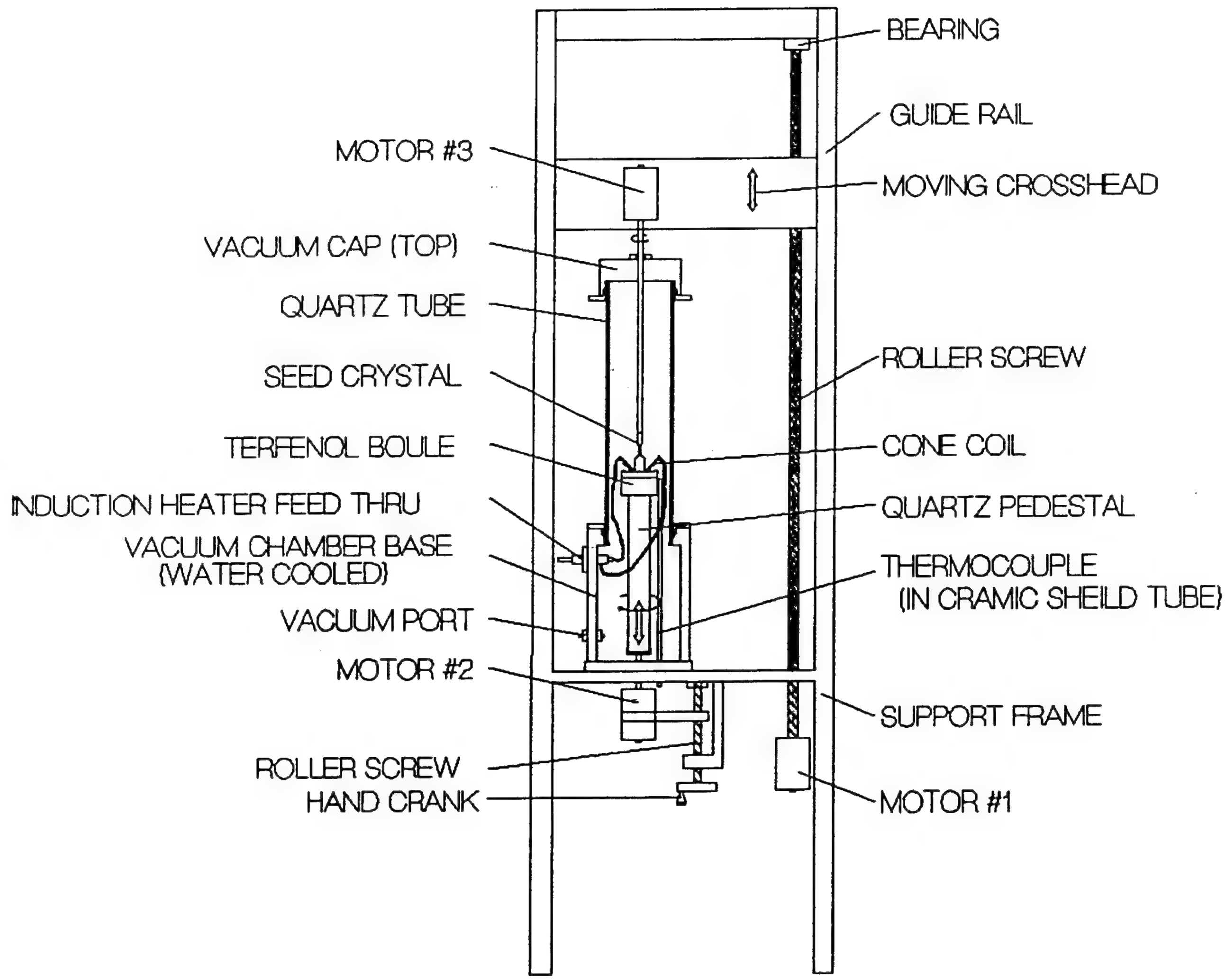
THM APPARATUS PARTS LIST
1/13/93
R. DALEY
FILE: THMNLT.DOC

PART	NUMBER RQ'D	ESTIMATED COST	REQUIRED NLT DATE	DESIGN PRIORITY
MAIN QUARTZ TUBE	1	160.00	3/26/93	1
DRIVE MOTOR & RESOLVER	1	1200.00	3/26/93	2
REDUCTION GEARING	1	1300.00	3/26/93	2
DRIVE AMP/CONTROLLER	1	3750.00	3/26/93	3
HEATING ELEMENT	1 (+1)	1040.00	3/26/93	4
TERMINAL TUBE	1	40.00	3/26/93	4
CONNECTOR STRAP	4	INCLUDED	3/26/93	4
AL-SI BASEPLATE	1	200.00	3/26/93	5
CAP	1	200.00	3/26/93	5
INSULATOR SUPPORT TUBE	1	80.00	3/26/93	5
HEATING ELEMENT SUPPORT HARDWARE	Misc.	100.00	3/26/93	5
BEARINGS	2	100.00	3/26/93	6
FRAME	1	300.00	3/26/93	7
HEATER POWER SUPPLY/SCR	1	800.00	3/26/93	8
PtRh THERMOCOUPLE	2	600.00	3/26/93	9
TEMP CONTROLLER	1	350.00	3/26/93	10
TRANSFORMER	1	600.00	3/26/93	10
PULLEY SHAFT	1	200.00	3/26/93	11
PULLEY	3	75.00	3/26/93	12
TERFENOL RAW MATERIAL	Tb:2Kg Dy: 5 Kg Fe: 200 Kg	5400.00 3000.00 2800.00	3/26/93	12

TOTAL=22,295.00

FIGURE A-4

DASH METHOD
Apparatus Concept



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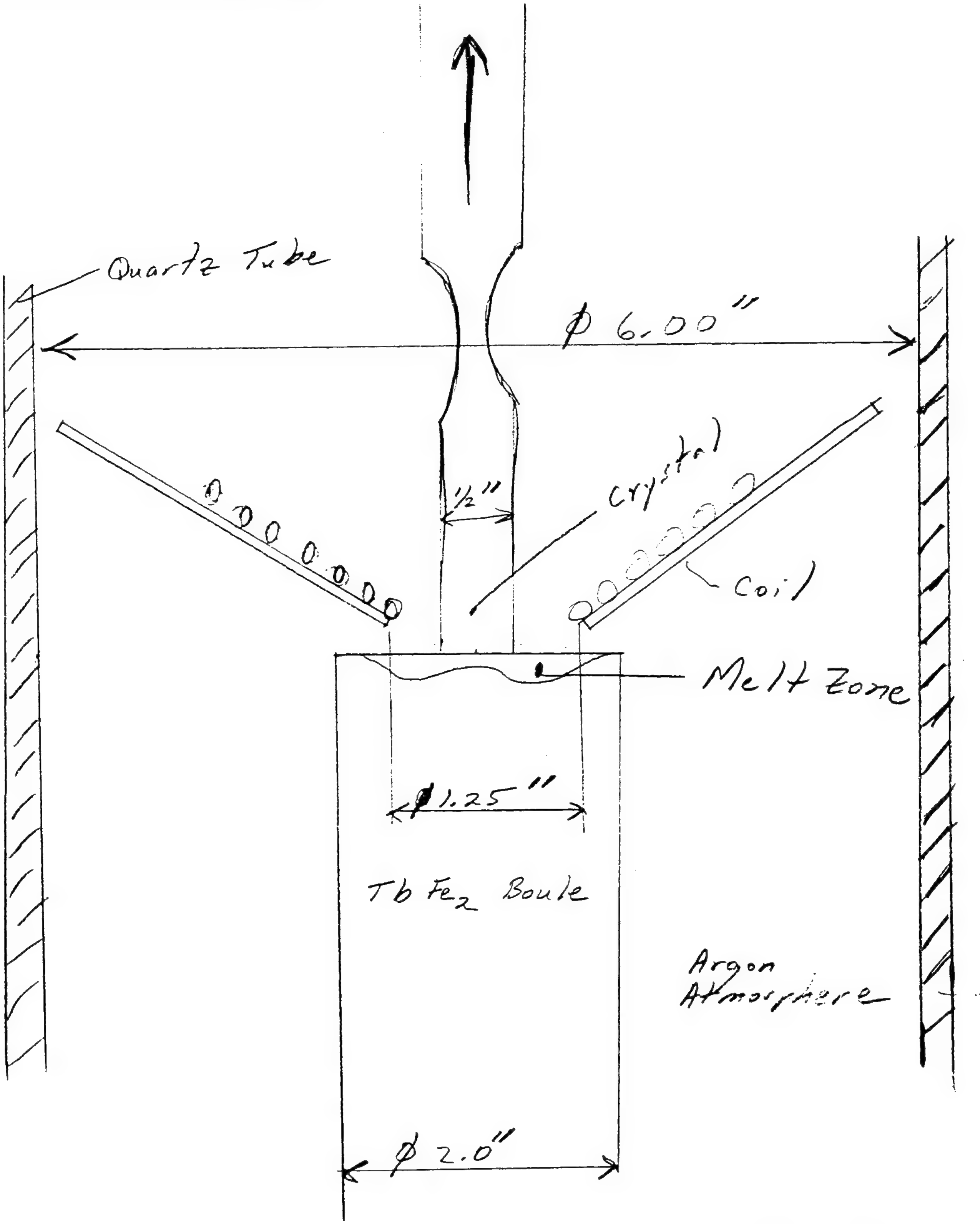
R. Daley 12/3/92

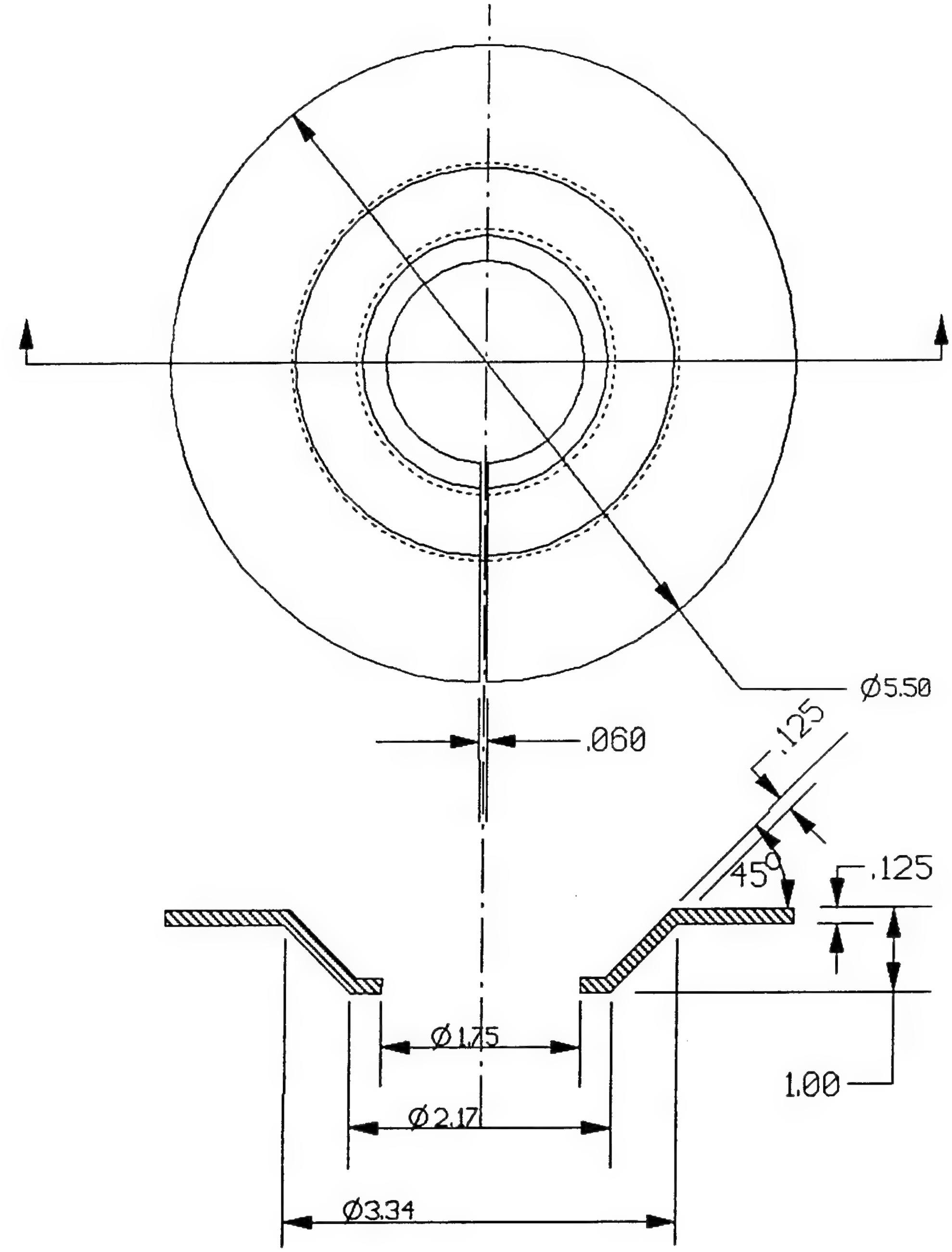
FIGURE A-5



We have Lepel T-20-3-KC-TL and Model SCR-120

450 KHZ
20 KW
SN 92047-12

FIGURE A-6A

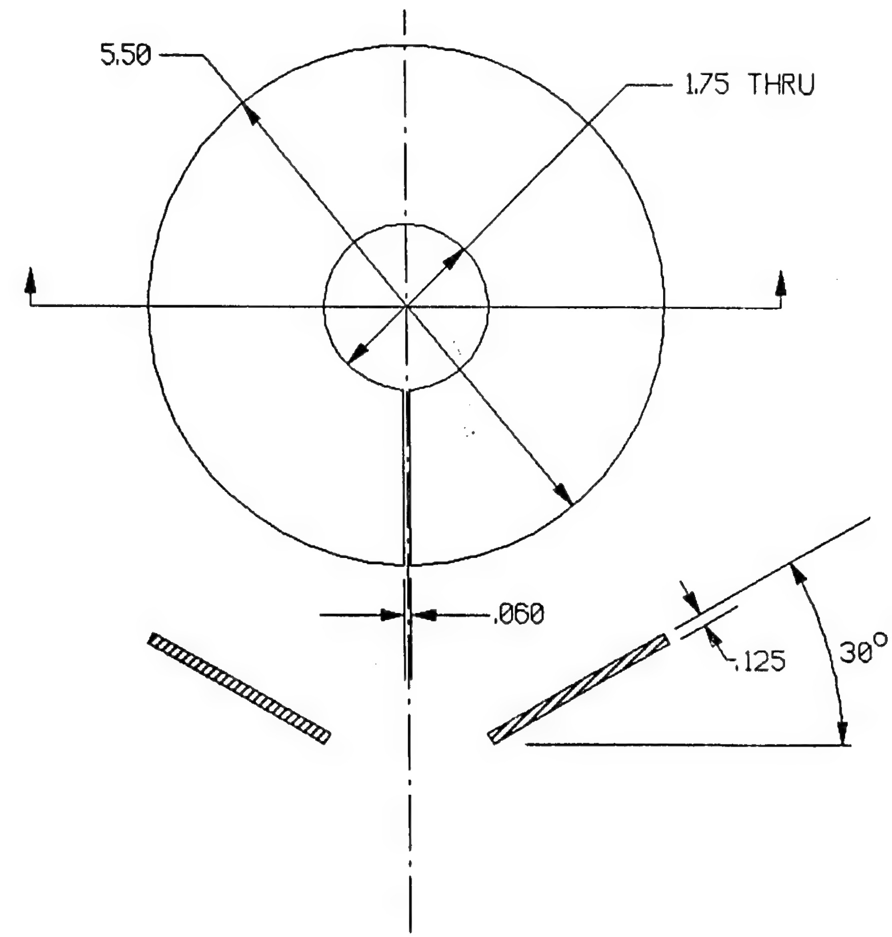


PANCAKE COIL

MATERIAL: COPPER: C11000

FILE: PCOIL.FCD

FIGURE A-6B



CONE COIL

MATERIAL: COPPER: C10200,C10400,C10500, OR C10700

FILE: CCOIL.FCD

FIGURE A-6C

Fully Developed, Turbulent Internal Flow; Constant Surface Temperature.

see Incropera & Dewitt pg 407, 397

$\Delta T = T_s - T_m$

$$\Delta T_{Lm} = \frac{\Delta T_o - \Delta T_i}{\ln\left[\Delta T_o / \Delta T_i\right]}$$

Assume Constant surface Temp. T_{mi} and Max allowable T_{mo} Known $\Rightarrow$ ΔT_{Lm} Known

All Fluid Properties Evaluated at $\overline{T_m} = \frac{T_{mi} + T_{mo}}{2}$

$$q = \dot{m}\, C_p \left(T_{mo} - T_{mi}\right) = \bar{h}\left(\pi D L\right)\Delta T_{Lm}$$

$$\bar{h} = \frac{\overline{Nu}_D\, k}{D}$$

$$\Rightarrow \dot{m}\, C_p \left(T_{mo} - T_{mi}\right) = \overline{Nu}_D\, k\, \pi L\, \Delta T_{Lm}$$

$$\overline{Nu}_D = .027\, R^{4/5}\, Pr^{1/3}\left(\frac{\mu}{\mu_s}\right)^{.14}$$

$$\Rightarrow \dot{m}\, C_p \left(T_{mo} - T_{mi}\right) = .027\, R^{4/5}\, Pr^{1/3}\left(\frac{\mu}{\mu_s}\right)^{.14} k\, \pi L\, \Delta T_{Lm}$$

$$R = \frac{D u_m}{\nu} \qquad u_m = \frac{\dot{m}}{\rho A} = \frac{\dot{m}\, 4}{\rho \pi D^2}$$

$$\Rightarrow R = \frac{D\, \dot{m}\, 4\, \rho}{\rho \pi D^2 \mu} = \frac{4 \dot{m}}{\pi D \mu}$$

$$\Rightarrow \dot{m}\, C_p \left(T_{mo} - T_{mi}\right) = (.027)\left(Pr^{1/3}\right)\left(\frac{\mu}{\mu_s}\right)^{.14}\left(k\, \pi L\right)\left(\Delta T_{Lm}\right)\left(\frac{4 \dot{m}}{\pi D \mu}\right)^{4/5}$$

$$\Rightarrow \dot{m}^{.2} = \frac{(.10291)\left(Pr^{1/3}\right)\left(\frac{\mu}{\mu_s}\right)^{.14}\left(k L\, \Delta T_{Lm}\right)\left(\frac{1}{D\mu}\right)^{.8}}{C_p\left(T_{mo} - T_{mi}\right)}$$

$$\Rightarrow \boxed{\dot{m} = (1.154)\left(10^{-5}\right)\left[\frac{\left(Pr^{1.67}\right)\left(\frac{\mu}{\mu_s}\right)^{.7} k^5 \left(\Delta T_{Lm}\right)^5}{C_p^5 \left(T_{mo} - T_{mi}\right)^5 D^4 \mu^4}\right] L^5}$$

FIGURE A-7A

Assume T_{m_i} = room = 295
T_{m_o} = 90°C = 363

Note 20 Kw Generator

$$\dot{m} = \frac{q}{C_p \Delta T} = \frac{20000}{(4184)(68)} = \boxed{.0703\ Kg/s}$$

$\bar{T}_m = 329 \approx 330$
$C_p = 4184$
$\mu = 489(10^{-6})$
$k = .650$
$Pr = 3.15$

$$D = \frac{.25 - 2(.030)}{39.37} = 4.826(10^{-3})$$

$\mu_s = ??$

Simpler Form: $Nu_D = .023\ Re^{.8}\ Pr^{.4}$

$$\Rightarrow \dot{m}\ C_p\ (T_{m_o} - T_{m_i}) = .023\ k\ \pi\ L\ \Delta T_{Lm}\ Pr^{.4}\left(\frac{4\dot{m}}{\pi D \mu}\right)^{.8}$$

$$= \frac{.08766\ k\ L\ \Delta T_{Lm}\ Pr^{.4}\ \dot{m}^{.8}}{D^{.8}\mu^{.8}}$$

$$\Rightarrow \dot{m} = [5.176(10^{-6})]\left[\frac{k^5 (\Delta T_{Lm})^5\ Pr^2\ L^5}{D^4 \mu^4\ C_p^5\ (T_{m_o} - T_{m_i})^5}\right]$$

$$\boxed{\dot{m} = \frac{5.176(10^{-6})\ Pr^2}{(D\mu)^4}\left(\frac{k\ \Delta T_{Lm}\ L}{C_p(T_{m_o} - T_{m_i})}\right)^5}$$

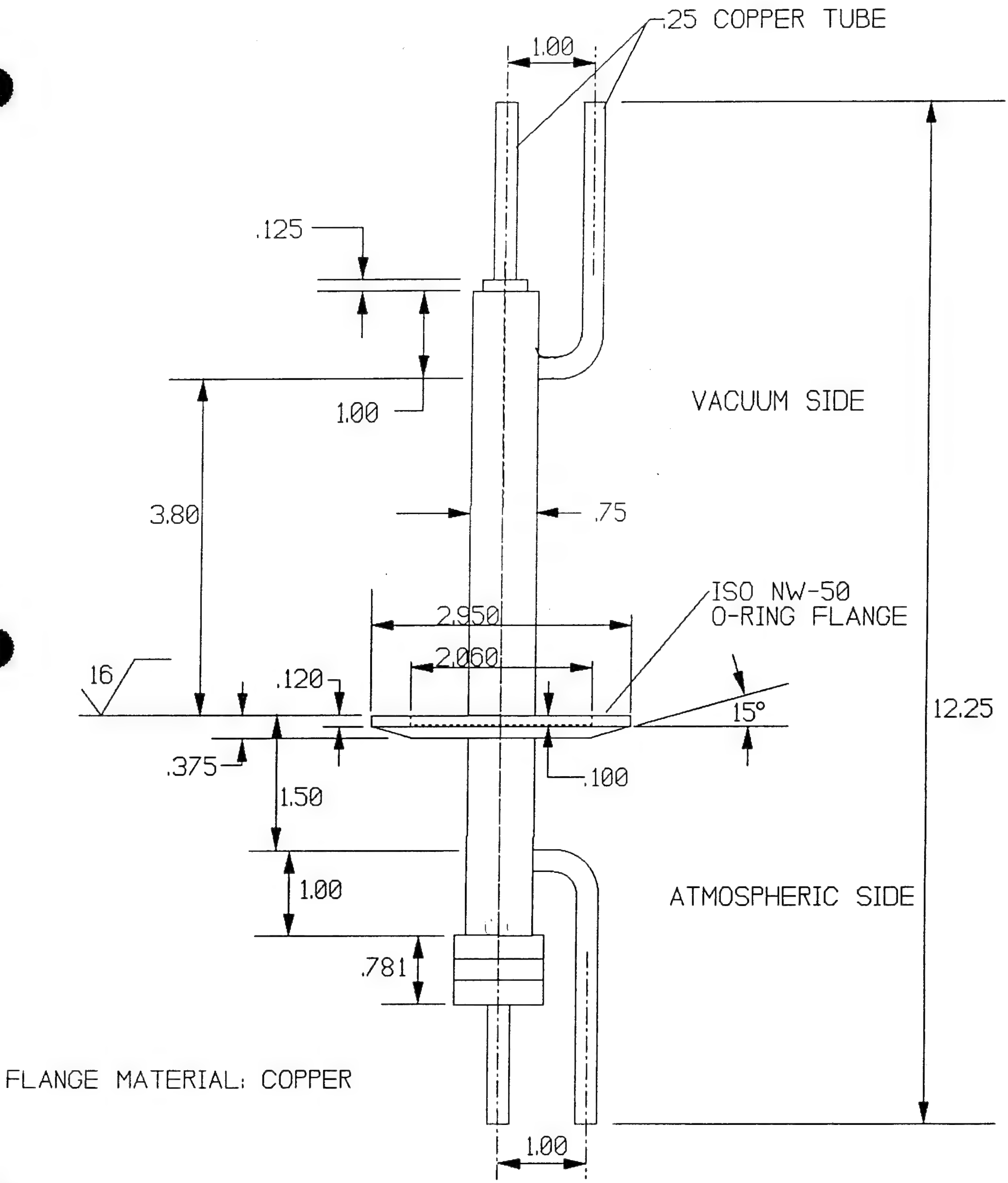
$.0703 = 1.0306(10^{-10})\ L^5\ \Delta T_{Lm}^5$

$6.821(10^8) = L^5\ \Delta T_{Lm}^5$

Assume $L = \frac{\pi(5'')\ 6\ \text{coils}}{39.37} \Rightarrow \Delta T_{Lm} = 24.41$

Assume $T_s = 94°C \Rightarrow$ $\Delta T_i = 94 - 22 = 72$ $\quad \Delta T_{Lm} = 23.5$
$\Delta T_o = 94 - 90 = 4$ $\quad$ Close!

FIGURE A-7B



.25 COPPER TUBE
1.00
.125
1.00
VACUUM SIDE
3.80
.75
ISO NW-50
O-RING FLANGE
2.950
2.060
16
.120
15°
12.25
.375
.100
1.50
1.00
ATMOSPHERIC SIDE
.781
FLANGE MATERIAL: COPPER
1.00

FIGURE A-8

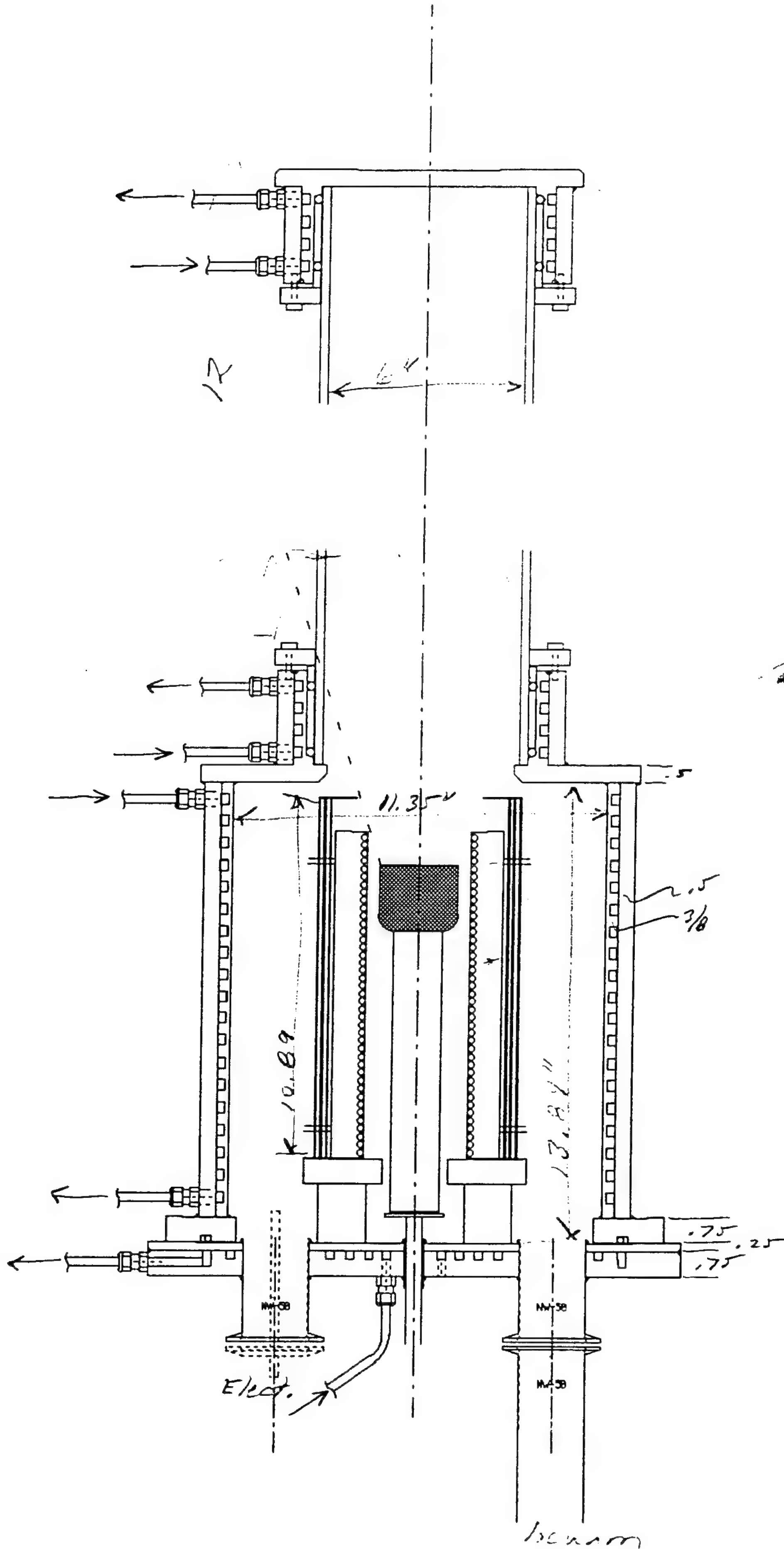


FIGURE A-9A

CZ512E-5

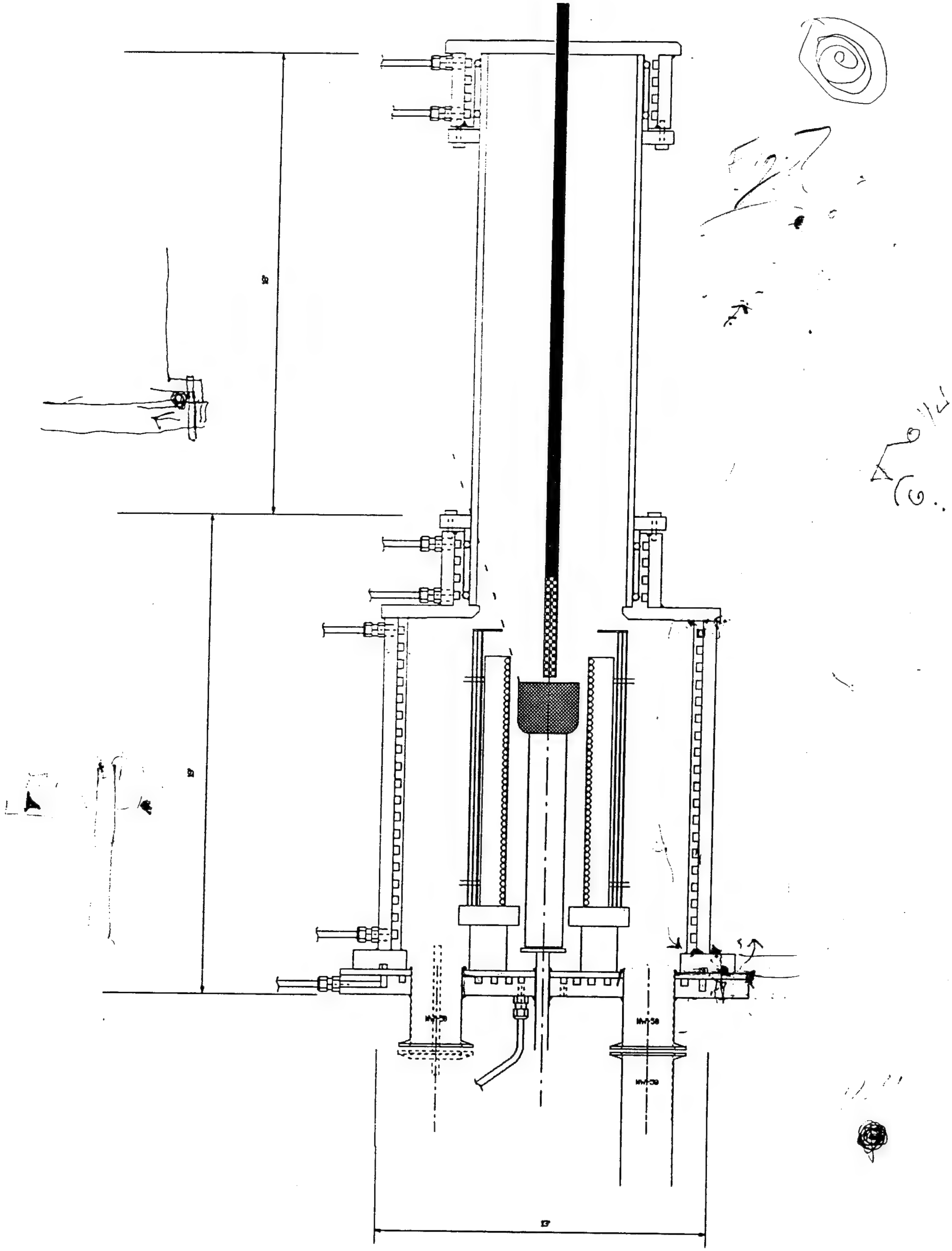
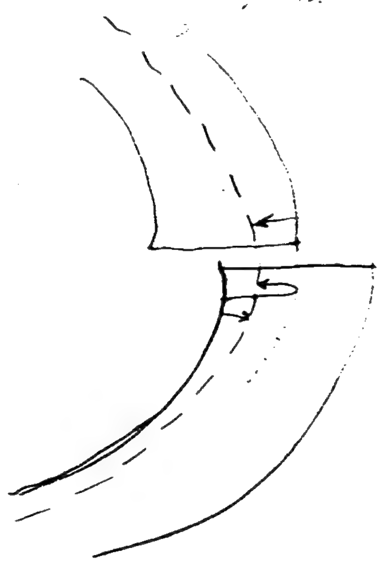


FIGURE A-9B

Shrink Fit of Aluminum Tubes:

$$\Delta T = \frac{D_f - D_i}{\alpha D_i}$$ Temp Required to Assemble the outer Component.

r_i ; R_i r_o , R_o



α 6061 T6 = 13-14 $(10^{-6})/°F$
To 572°F

P_f causes δ_i in inner cylinder

P_f causes δ_o on outer cylinder

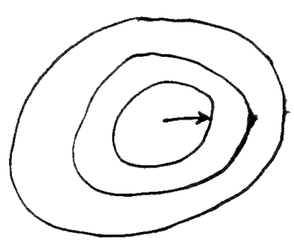
$$r_o + \delta_o = R_i + \delta_i$$

$(R_i - r_o)$ = Initial interference That must be overcome by heating outer cylinder

and $(R_i - r_o) = \delta_o - \delta_i$
This is the "shrinkage Allowance" Δ

⇒ Start by Determining The temperature difference allowable, this gives Δ achievable → P_f → Determine stresses

Effect of internal Pressure:



P_i causes some expansion of r_o and r_i
These two Expansions must be equal.

$$\Delta T = \frac{D_f - D_i}{\alpha D_i} = \frac{\Delta}{\alpha r_o} \qquad \Delta = (\Delta T)\alpha r_o$$

FIGURE A-10A

$$\Delta = \alpha r_0 (\Delta T)$$

$$\Rightarrow P_f = \frac{\Delta (E)(R_0^2 - r_0^2)(r_0^2 - r_i^2)}{2 r_0^3 (R_0^2 - r_i^2)}$$

$$R_1 = r_0 + \Delta$$

<u>Shrink Fit Stresses:</u>

$$\sigma_{hi} = -\frac{P_f R_i^2 (2)}{(R_i^2 - r_i^2)}$$

both at inner radius

$$\sigma_{h_0} = \frac{P_f r_0^2}{(R_0^2 - r_0^2)}\left(1 + \frac{R_0^2}{r_0^2}\right)$$

<u>With Internal Pressure, P</u>

Inner Cylinder

$$\sigma_i^* = \sigma_{hi} + \frac{P r_i^2}{(R_0^2 - r_i^2)}\left[1 + \left(\frac{R_0}{r_i}\right)^2\right]$$

Outer Cylinder

$$\sigma_0^* = \sigma_{h_0} + \frac{P r_i^2}{(R_0^2 - r_i^2)}\left[1 + \left(\frac{R_0}{r_0}\right)^2\right]$$

FIGURE A-10 B

Shrink Fit: Practical Tolerances

Assume $R_i = X \pm .002$
$r_o = Y \pm .002$

To insure at least 1mil of interference:

$$R_i - r_o = .001 = (X - .002) - (Y + .002)$$
$$= (X - Y) - .004 \Rightarrow X - Y = .005$$

$\Rightarrow$ Design for 5 mils nominal interference.

Then maximum interference would be

$$\Delta max = R_i - r_o = (X + .002) - (Y - .002)$$
$$= (X - Y) + .004$$
$$= .005 + .004 = \underline{.009}$$

Analysis shows stresses in this case are acceptable (<9 Ksi) and dT required would be 128°F $\Rightarrow$ OK.

Note that if at least 0 mils of interference are acceptable

$\Rightarrow$ Design for 4 mils interference

$$\Delta max = .008$$

$(dT)req. = 114.5\ °F$
Max Stress = 7.8 Ksi (at 20psi)

FIGURE A-10C

```
================================ VARIABLE SHEET ================================
St Input---- Name--- Output--- Unit----- Comment---------------------------------
                                         **********************************
                                         SHRNKFIT.TK
                                         SHRINK FIT CALCULATIONS FOR
                                         CONCENTRIC CYLINDERS OF SAME MATERIAL
                                         WITH FINAL INTERNAL PRESSURE
                                         SUPERIMPOSED
                                         **********************************
   5.375     ro                          INNER RADIUS OF OUTER CYLINDER
   5.75      Ro                          OUTER RADIUS OF OUTER CYLINDER
   5         ri                          INNER RADIUS OF INNER CYLINDER
             Ri      5.3847825 (OUTPUT)  OUTER RADIUS OF INNER CYLINDER

   .000013   alpha                       THERMAL EXPANSION COEFFICIENT
   140       dT                          TEMPERATURE DIFFERENTIAL
   1E7       E                           YOUNG'S MODULUS
             DELTA   .0097825            SHRINKAGE ALLOWANCE

             Pf      634.11115           SHRINK FIT PRESSURE
             SFhi    -9202.779           SHRINK FIT STRESS; HOOP; INNER CYL.
             SFho    9416.6693           SHRINK FIT STRESS; HOOP; OUTER CYL.

   20        P                           INTERNAL PRESSURE
             SPhi    -9058.748           PRESSURIZED STRESS; HOOP; INNER CYL.
             SPho    9549.6555           PRESSURIZED STRESS; HOOP; INNER CYL.

================================ RULE SHEET ====================================
  Rule---------------------------------------------------------------------------
  DELTA=alpha*ro*dT
  Pf=DELTA*E*(Ro^2-ro^2)*(ro^2-ri^2)/(2*ro^3*(Ro^2-ri^2))
  Ri=ro+DELTA
  SFhi=-Pf*2*Ri^2/(Ri^2-ri^2)
  SFho=Pf*ro^2*(1+(Ro/ro)^2)/(Ro^2-ro^2)
  SPhi=SFhi+P*ri^2*(1+(Ro/ri)^2)/(Ro^2-ri^2)
  SPho=SFho+P*ri^2*(1+(Ro/ro)^2)/(Ro^2-ri^2)
```

FIGURE A-11A

VARIABLE SHEET

St	Input	Name	Output	Unit	Comment
					**********************************
					SHRNKFIT.TK
					SHRINK FIT CALCULATIONS FOR
					CONCENTRIC CYLINDERS OF SAME MATERIAL
					WITH FINAL INTERNAL PRESSURE
					SUPERIMPOSED
					**********************************
	5.375	ro			INNER RADIUS OF OUTER CYLINDER
	5.75	Ro			OUTER RADIUS OF OUTER CYLINDER
	5	ri			INNER RADIUS OF INNER CYLINDER
		Ri	5.376	(OUTPUT)	OUTER RADIUS OF INNER CYLINDER
	.000013	alpha			THERMAL EXPANSION COEFFICIENT
		dT	14.31127		TEMPERATURE DIFFERENTIAL
	1E7	E			YOUNG'S MODULUS
	.001	DELTA			SHRINKAGE ALLOWANCE
		Pf	64.820971		SHRINK FIT PRESSURE
		SFhi	-960.3869		SHRINK FIT STRESS; HOOP; INNER CYL.
		SFho	962.60356		SHRINK FIT STRESS; HOOP; OUTER CYL.
	20	P			INTERNAL PRESSURE
		SPhi	-816.3559		PRESSURIZED STRESS; HOOP; INNER CYL.
		SPho	1095.5898		PRESSURIZED STRESS; HOOP; INNER CYL.

VARIABLE SHEET

St	Input	Name	Output	Unit	Comment
					**********************************
	5.375	ro			INNER RADIUS OF OUTER CYLINDER
	5.75	Ro			OUTER RADIUS OF OUTER CYLINDER
	5	ri			INNER RADIUS OF INNER CYLINDER
		Ri	5.38	(OUTPUT)	OUTER RADIUS OF INNER CYLINDER
	.000013	alpha			THERMAL EXPANSION COEFFICIENT
		dT	71.556351		TEMPERATURE DIFFERENTIAL
	1E7	E			YOUNG'S MODULUS
	.005	DELTA			SHRINKAGE ALLOWANCE
		Pf	324.10485		SHRINK FIT PRESSURE
		SFhi	-4756.627		SHRINK FIT STRESS; HOOP; INNER CYL.
		SFho	4813.0178		SHRINK FIT STRESS; HOOP; OUTER CYL.
	20	P			INTERNAL PRESSURE
		SPhi	-4612.596		PRESSURIZED STRESS; HOOP; INNER CYL.
		SPho	4946.004		PRESSURIZED STRESS; HOOP; INNER CYL.

VARIABLE SHEET

St	Input	Name	Output	Unit	Comment
					**********************************
	5.375	ro			INNER RADIUS OF OUTER CYLINDER
	5.75	Ro			OUTER RADIUS OF OUTER CYLINDER
	5	ri			INNER RADIUS OF INNER CYLINDER
		Ri	5.384	(OUTPUT)	OUTER RADIUS OF INNER CYLINDER
	.000013	alpha			THERMAL EXPANSION COEFFICIENT
		dT	128.80143		TEMPERATURE DIFFERENTIAL
	1E7	E			YOUNG'S MODULUS
	.009	DELTA			SHRINKAGE ALLOWANCE

FIGURE A-11B

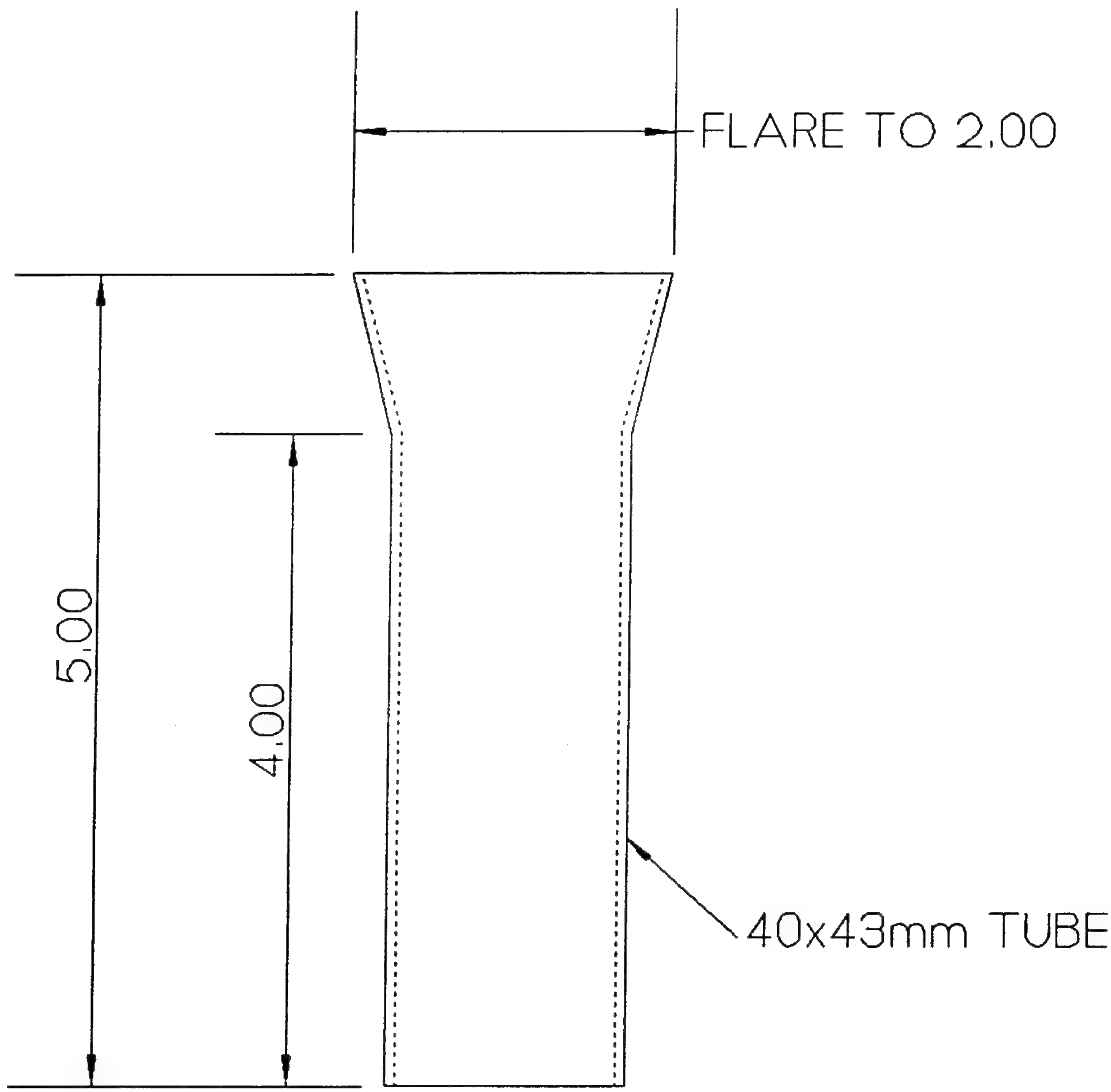
VARIABLE SHEET

St	Input	Name	Output	Unit	Comment
					**********************************
	5.375	ro			INNER RADIUS OF OUTER CYLINDER
	5.75	Ro			OUTER RADIUS OF OUTER CYLINDER
	5	ri			INNER RADIUS OF INNER CYLINDER
		Ri	5.379	(OUTPUT)	OUTER RADIUS OF INNER CYLINDER
	.000013	alpha			THERMAL EXPANSION COEFFICIENT
		dT	57.245081		TEMPERATURE DIFFERENTIAL
	1E7	E			YOUNG'S MODULUS
	.004	DELTA			SHRINKAGE ALLOWANCE
		Pf	259.28388		SHRINK FIT PRESSURE
		SFhi	-3814.292		SHRINK FIT STRESS; HOOP; INNER CYL.
		SFho	3850.4142		SHRINK FIT STRESS; HOOP; OUTER CYL.
	20	P			INTERNAL PRESSURE
		SPhi	-3670.261		PRESSURIZED STRESS; HOOP; INNER CYL.
		SPho	3983.4004		PRESSURIZED STRESS; HOOP; INNER CYL.

FIGURE A-11C

	Pf	583.38874	SHRINK FIT PRESSURE
	SFhi	-8482.077	SHRINK FIT STRESS; HOOP; INNER CYL.
	SFho	8663.432	SHRINK FIT STRESS; HOOP; OUTER CYL.
20	P		INTERNAL PRESSURE
	SPhi	-8338.046	PRESSURIZED STRESS; HOOP; INNER CYL.
	SPho	8796.4182	PRESSURIZED STRESS; HOOP; INNER CYL.

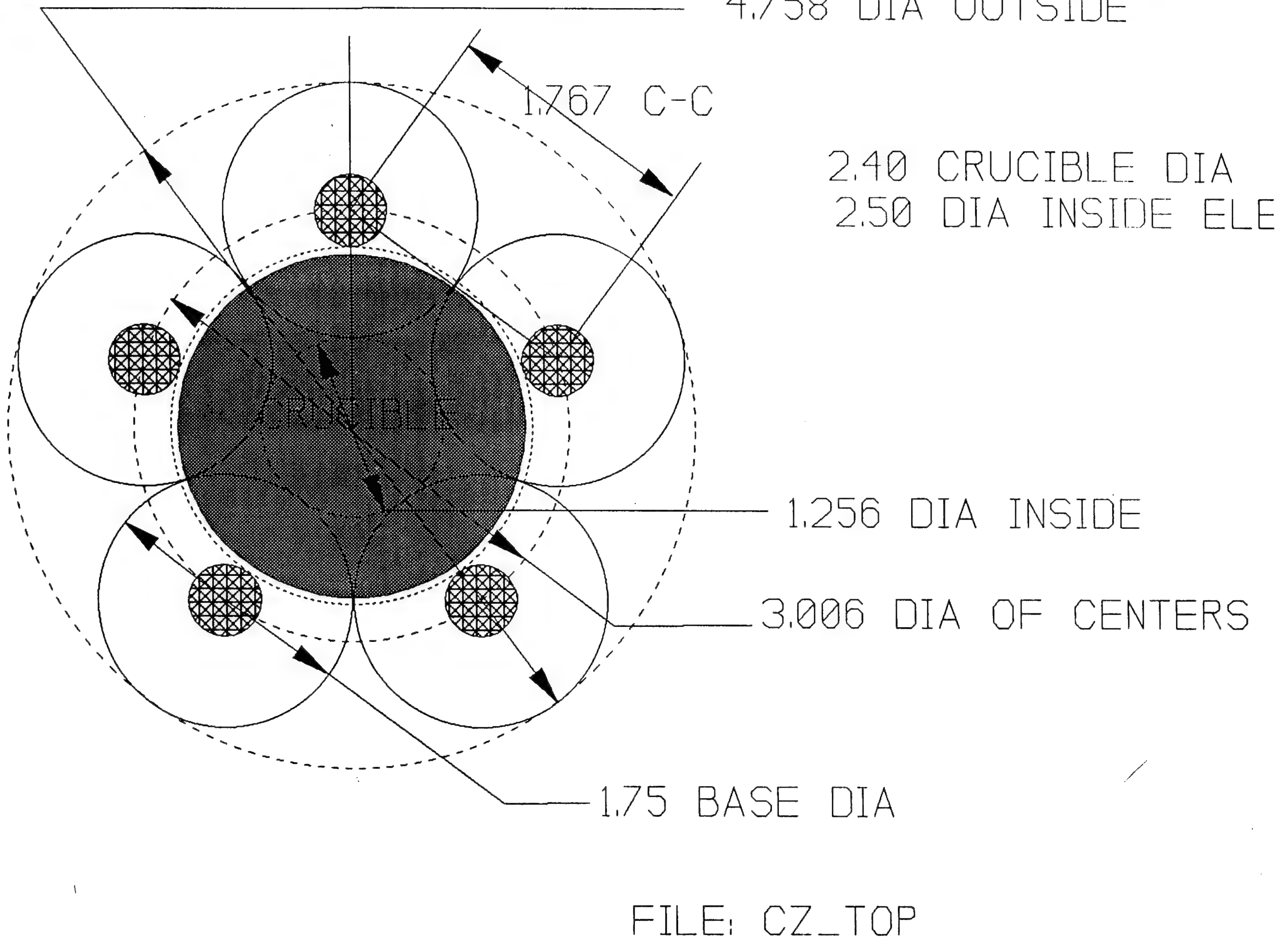
FIGURE A-11D



UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES TOLERANCES: ANGULAR ± 2 PLACE DECIMALS ± .060 3 PLACE DECIMALS ± .010	DRAWN	Rick Daley	EDO CORPORATION	ELECTRO ACOUSTIC DIVISION	
	CHECKED				
	STRESS	Rick Daley	DRAWING TITLE:		
DO NOT SCALE THIS DRAWING	ENGRG	Rick Daley	CRUCIBLE PEDISTAL		
MATERIAL:	RELEASE DATE				
QUARTZ TUBING	APPROVED		SIZE A	CODE IDENT NO. 24338	DWG NO. 2446RD3 ☐
	SC: 05-2446-33		SCALE: NONE		SHEET: 1 OF 1

FILE: QPEDESTL.FCD

FIGURE A-12



4.758 DIA OUTSIDE
1.767 C-C
2.40 CRUCIBLE DIA
2.50 DIA INSIDE ELE
CRUCIBLE
1.256 DIA INSIDE
3.006 DIA OF CENTERS
1.75 BASE DIA
FILE: CZ_TOP

FIGURE A-13A

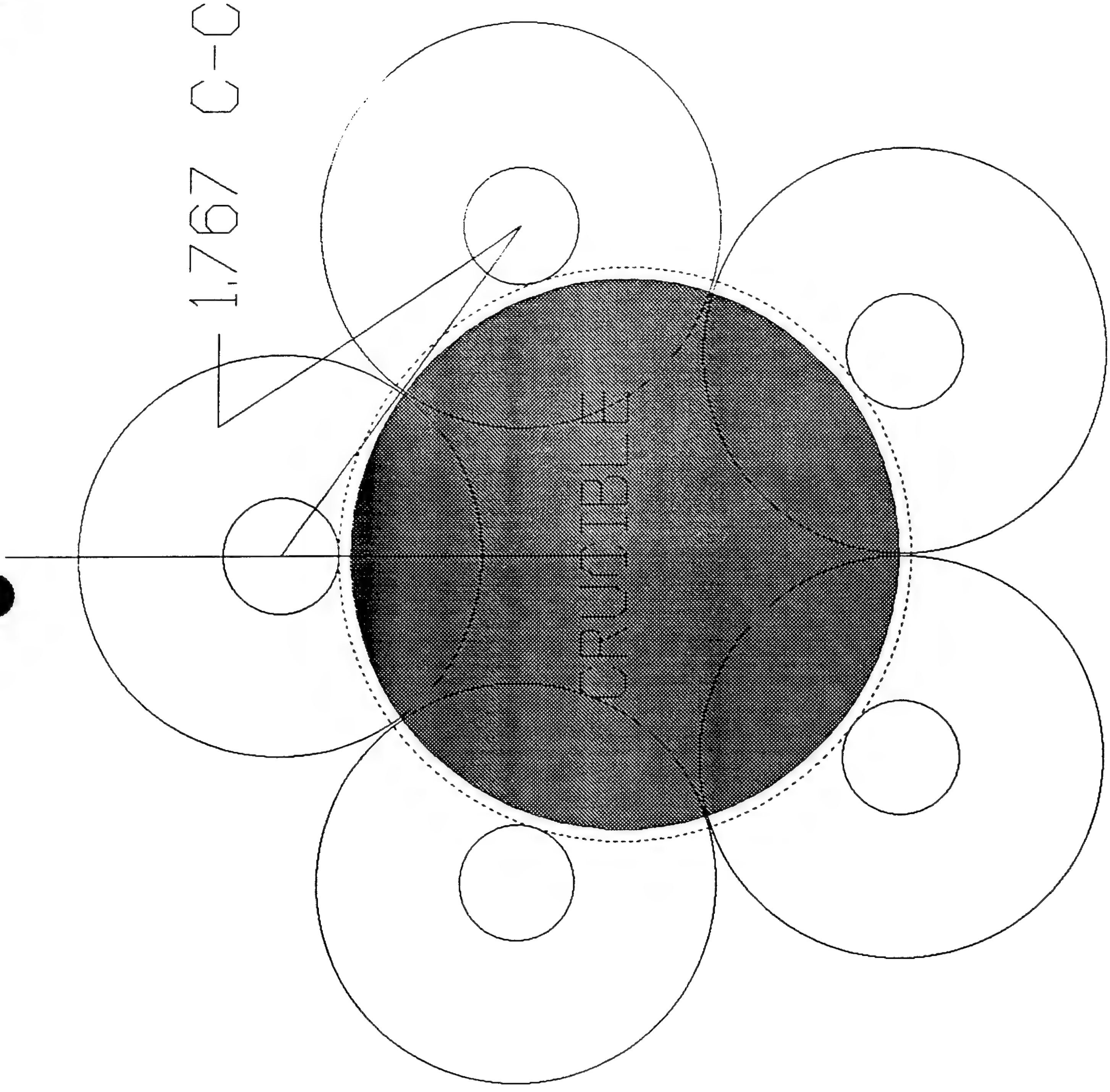


FIGURE A-13 B

DASH(CZ) APPARATUS PARTS LIST
1/13/93
R. DALEY
FILE: DASHNLT.DOC

PART	NUMBER RQ'D	ESTIMATED COST	REQUIRED NLT DATE	DESIGN PRIORITY
CONE COIL	1	2200.00	ASAP for P.O.P	1 IN PROGRESS
QUARTZ TUBE	1	500.00	4/12/93	2
MOTOR #1 & GEAR REDUCTION (CROSSHEAD MOTION)	1	2500.00	4/12/93	3
MOTOR #2 (BOULE ROTATION)	1	725.00	4/12/93	4
MOTOR #3 (SEED ROTATION)	1	725.00	4/12/93	5
ROLLER SCREW, BEARINGS FOR PULLING HEAD	1	750.00	4/12/93	6
ROLLER SCREW FOR BOULE MOTION	1	250.00	4/12/93	7
HAND CRANK/GEAR MECHANISM	1	400.00	4/12/93	8
GUIDE RAILS	2	750.00	4/12/93	9
INDUCTOR FEED THRU- Hi Voltage	1	420.00	4/12/93	10
* CURRENT FEED THRU- Hi Current	1	190.00	4/12/93	11
VACUUM NIPPLES	6	300.00	4/12/93	12
VACUUM MANIFOLD	1	200.00		
VACUUM VALVES	2	350.00	4/12/93	12
MISC. VACUUM CONNECTORS, COUPLINGS CLAMPS, CENTERING RINGS	16	500.00	4/12/93	12
CERAMIC TUBE FOR THERMOCOUPLE	2	150.00	4/12/93	13
*MOLY FURNACE ELEMENTS	2	440.00	4/12/93	14 ARRIVED
VACUUM CHAMBER - UPPER SECTION	1	3000.00	4/12/93	15
VACUUM CHAMBER - BASE SECTION	1	3000.00	4/12/93	15
TOP CAP/SEAL	1	1500.00	4/12/93	16
BEARINGS	6	200.00	4/12/93	17
BOULE PEDESTAL (QUARTZ)	1	80.00	4/12/93	18
APPARATUS FRAME	1	500.00	4/12/93	19
MOTOR #4 & GEAR REDUCTION (BOULE MOTION)		2500.00	4/12/93	20
AMP/MOTION CONTROLLER #1	1	3550.00	4/12/93	21
AMP/MOTION CONTROLLER #2	1	2340.00	4/12/93	22
AMP/MOTION CONTROLLER #3	1	2340.00	4/12/93	23

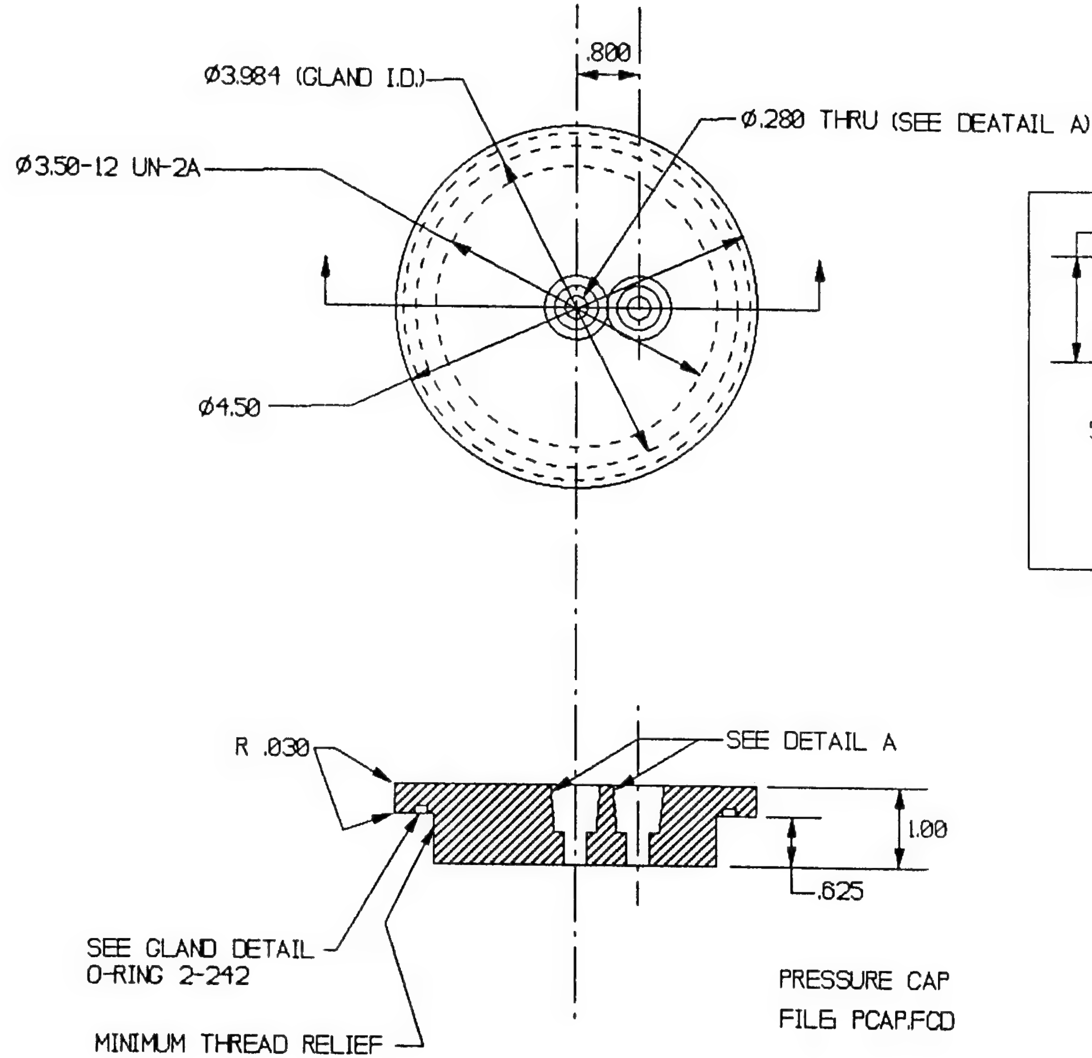
FIGURE A-14A

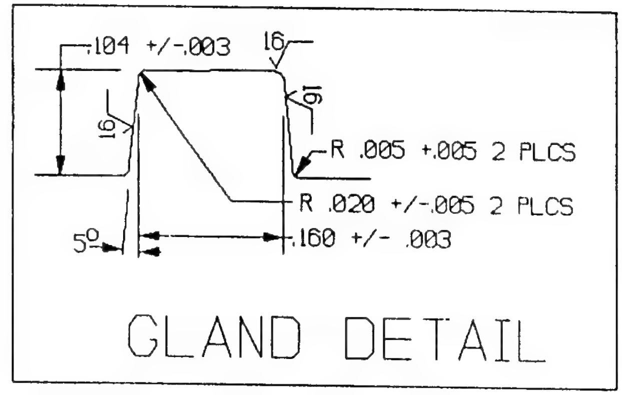
THERMOCOUPLE PtRh for melt	2	600.00	4/12/93	24
SCR	1	700.00	4/12/93	25
TEMPERATURE CONTROLLER	1	350.00	4/12/93	26
VACUUM GAUGE 10^{-7} TORR	1	2100.00	4/12/93	27
* TANTALUM SHIELD	1	1000.00	4/12/93	28
*MATERIAL FOR HEATER BASE STANDOFFS	1	20.00	4/12/93	28
VACUUM PUMP	1	5500.00	4/12/93	29 ARRIVED
* CRUCIBLES	4	1000.00	4/12/93	30
* CRUCIBLE PEDESTAL	1	80.00	4/12/93	31
MOTION CONTROLLER #4	0	2500.00	4/12/93	32
AMP/MOTION CONTROLLER #4	1	3550.00	4/12/93	33
O-RINGS	Misc.	50.00	4/12/93	34
CABLING FOR MOTORS/AMPS/CONTROLLERS	6	1200.00	4/12/93	35
TERFENOL RAW MATERIAL	Tb: 2 Kg Dy: 5 Kg Fe: ~~200~~ Kg 14	5400.00 3000.00 ~~2800.00~~ 280^{00}	3/26/93	36

*** CZ METHOD ONLY**

TOTAL = $61,210.00

FIGURE A-14 B





PRESSURE CAP

MATERIAL: ALUMINUM 6061-T6

FINISH: DEGREASE

FILE: PCAP.FCD

FIGURE A-15A

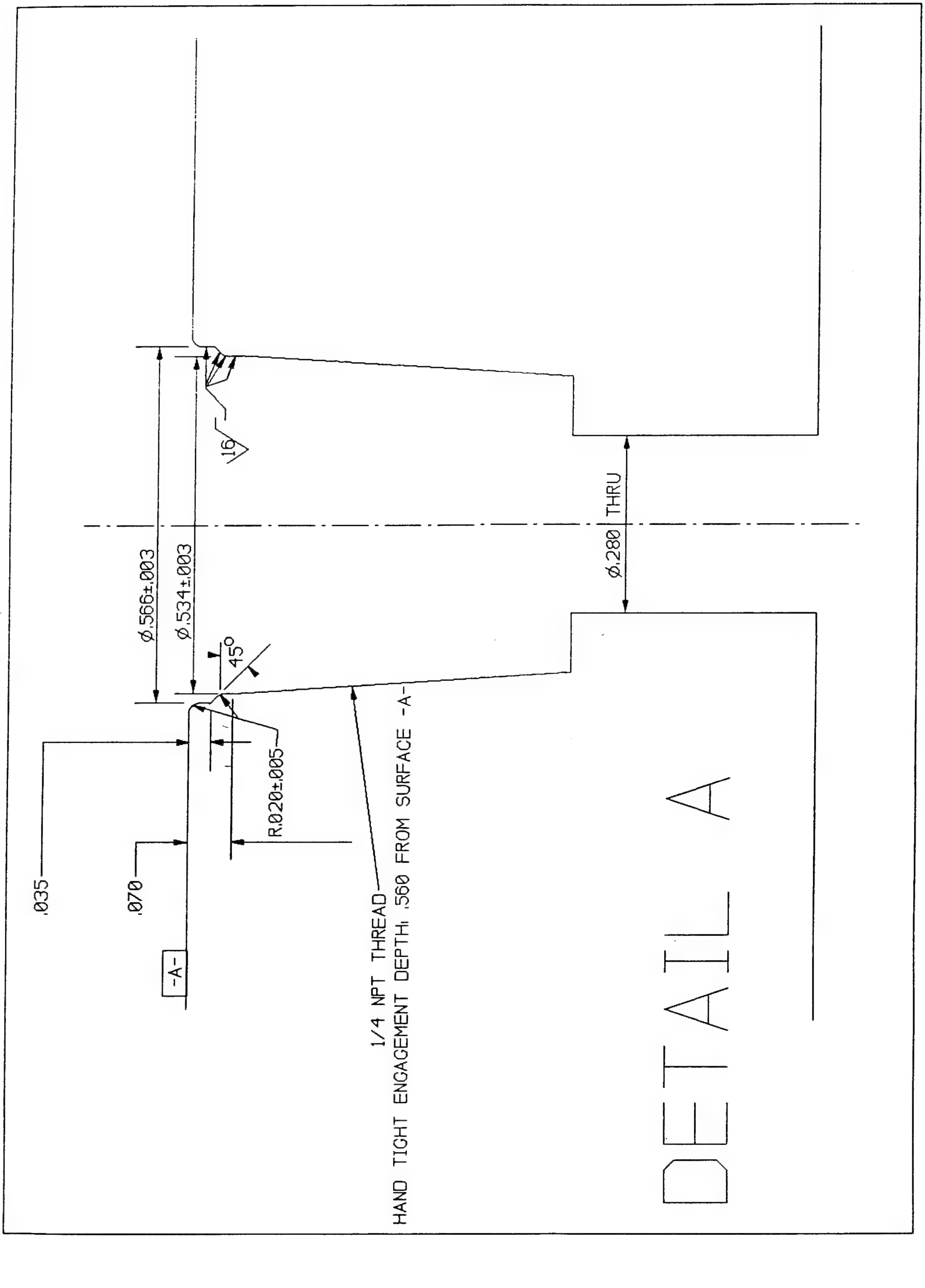
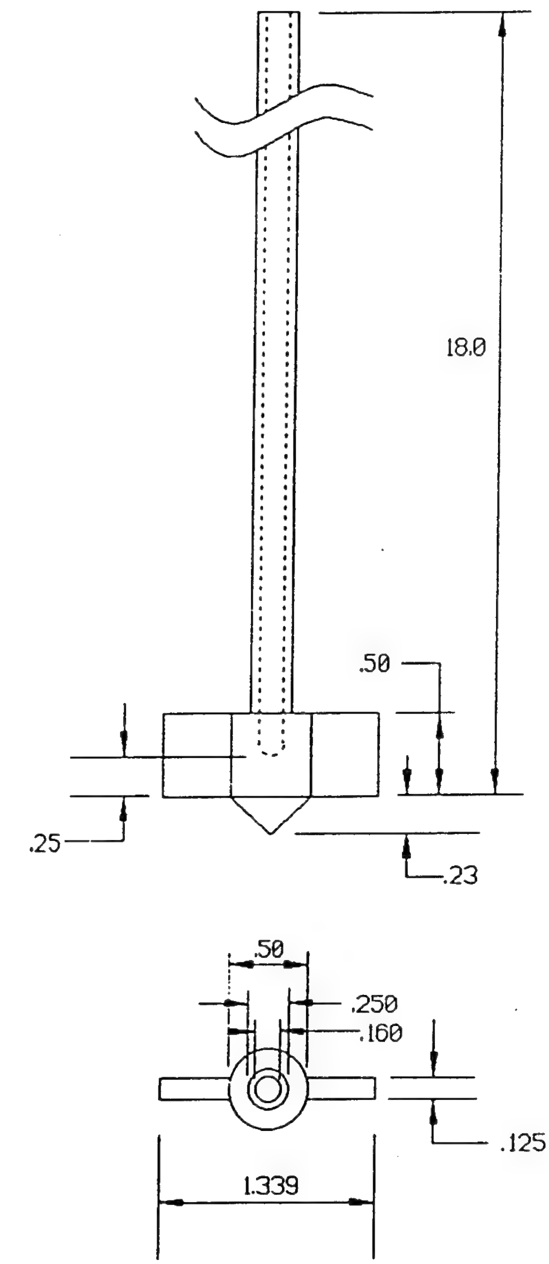

DETAIL A
1/4 NPT THREAD
HAND TIGHT ENGAGEMENT DEPTH, .560 FROM SURFACE -A-
Ø.566±.003
Ø.534±.003
Ø.280 THRU
45°
16
R.020±.005
.035
.070
-A-

FIGURE A-15B

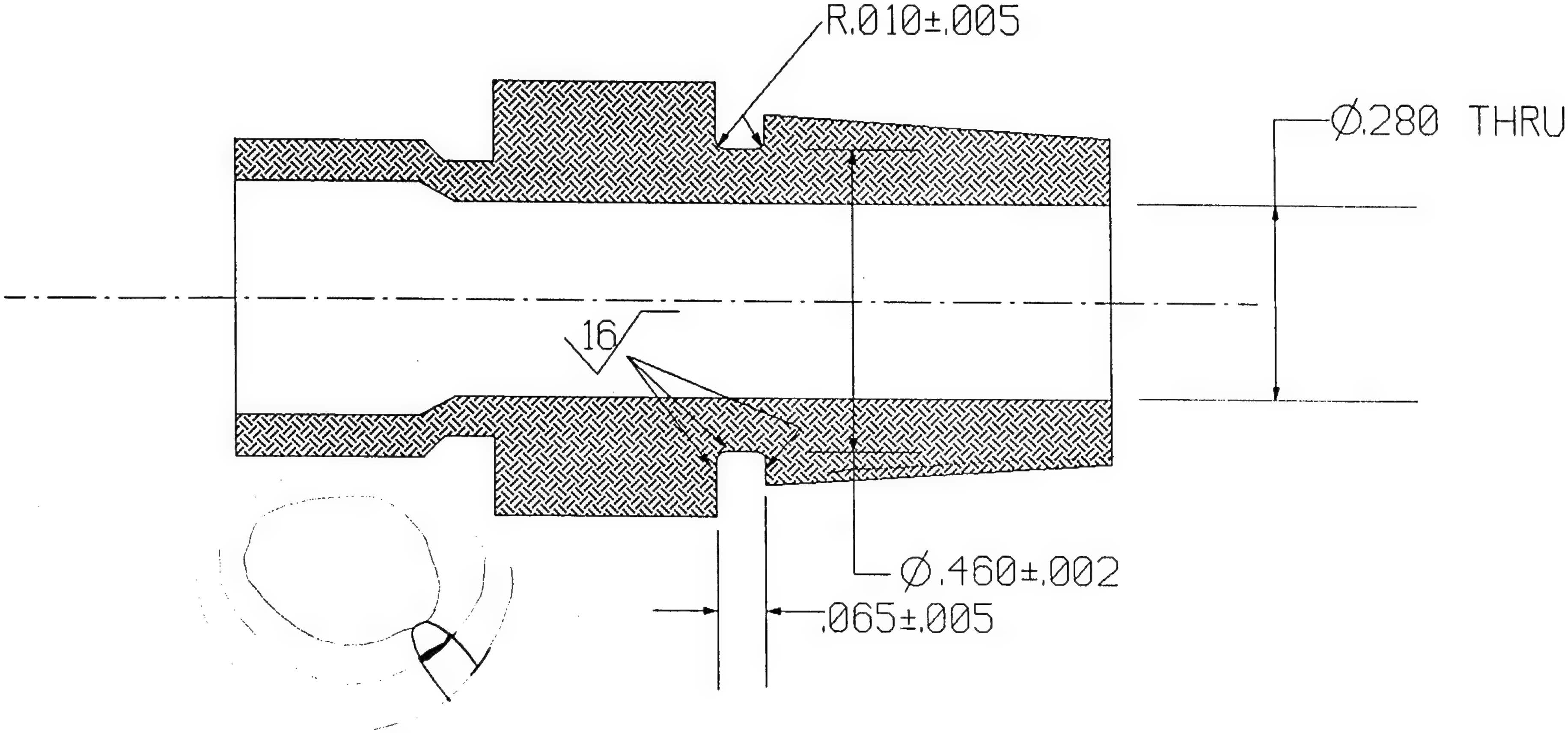
APPLICATION	REVISIONS



UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES TOLERANCES ANGULAR ± 1/2 DEGREE 2 PLACE DECIMALS ± .03 3 PLACE DECIMALS ± .010	DRAWN	Rick Daley	EDO CORPORATION	ELECTRO ACOUSTIC DIVISION
	CHECKED			
	STRESS	Rick Daley	DRAWING TITLE: PADDLE	
DO NOT SCALE THIS DRAWING	ENGRG	Rick Daley		
MATERIAL: YTTRIA	RELEASE DATE		SIZE: A	CODE IDENT NO. 24338
	APPROVED		DWG NO. 2446RD1	
	SC: 05-2446-33		SCALE: NONE	SHEET: 1 OF 1

FILE: PADDLE.FCD

FIGURE A-16



MODIFY BODY OF CAJON FITTING, PN SS-4-UT-1-4
ADD O-RING GROOVE AND BORE OUT CENTRAL HOLE
(O-RING 2-013)

FILE: CAJONMOD.FCD

FIGURE A-17A

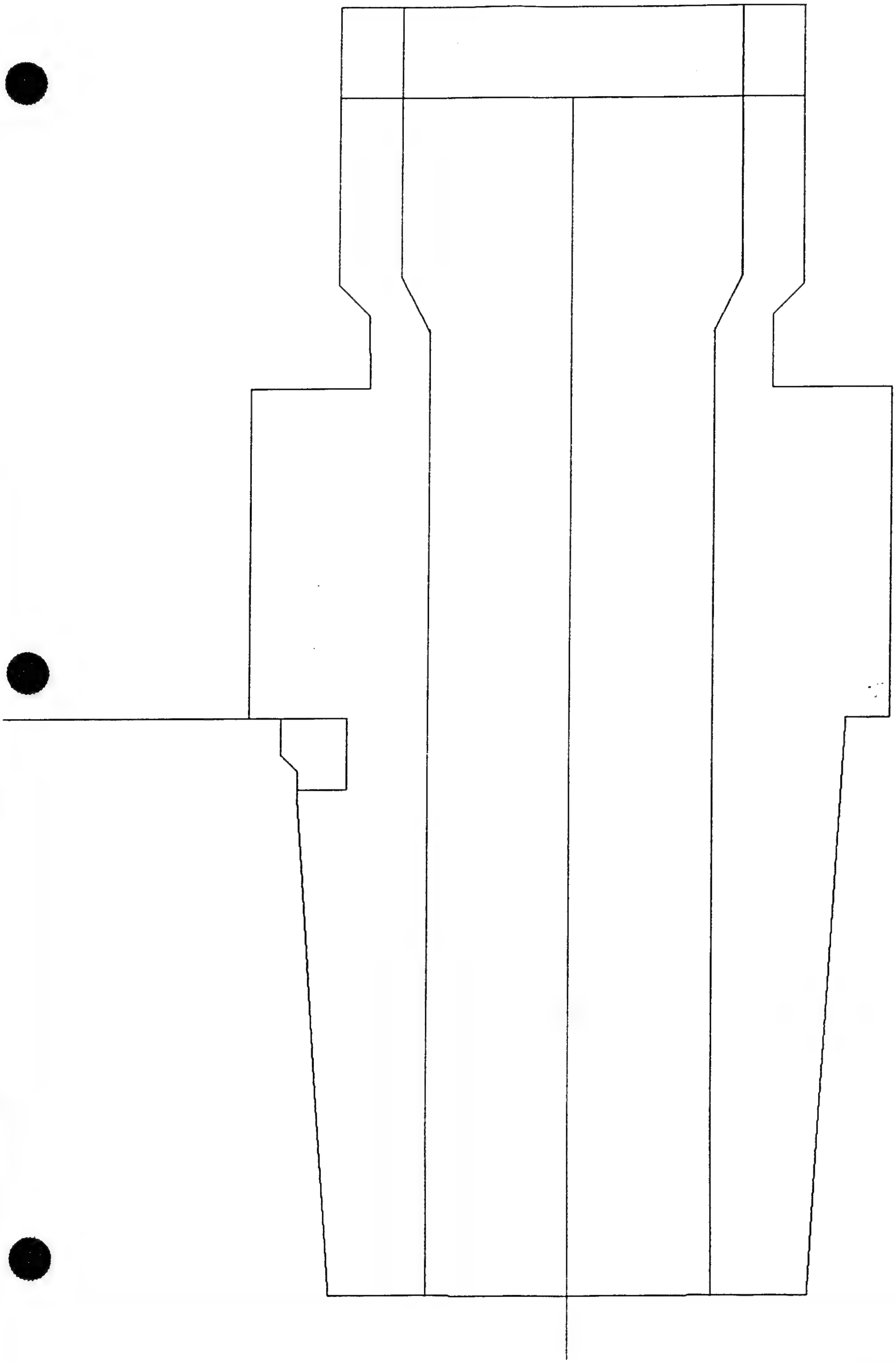
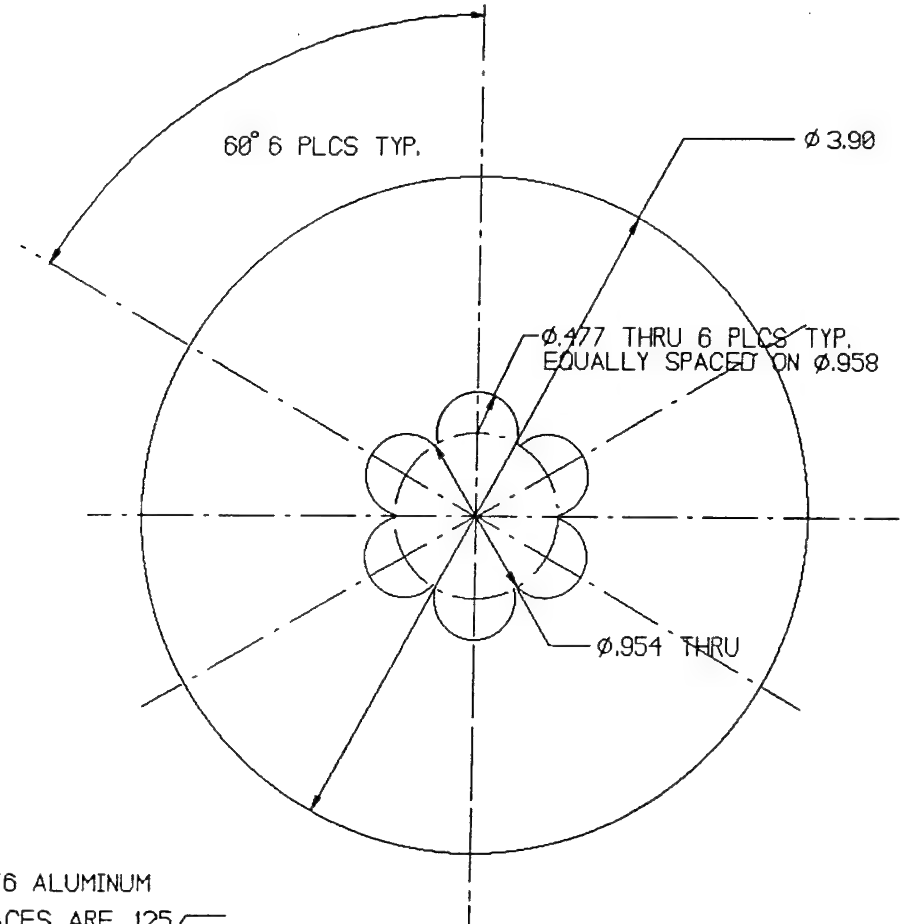


FIGURE A-17B



MATERIAL: 6061-T6 ALUMINUM
FINISH: ALL SURFACES ARE 125√
REMOVE SHARP EDGES; DEGREASE

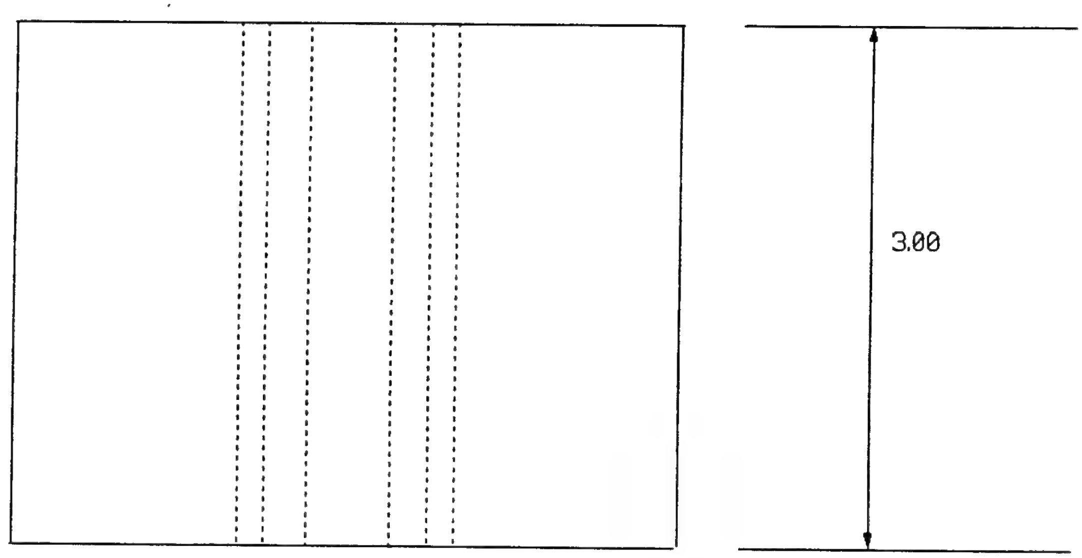


FIGURE A-18

Signal to Noise Limitation, Strain Gage Measurements

R. Daley

1 Active Gage

$$V_{out} = \left[\frac{R+\Delta R}{R+\Delta R+R} - \frac{R}{2R}\right] V_{in}$$

$$= \left[\frac{R+\Delta R}{2R+\Delta R} - \frac{1}{2}\right] V_{in}$$

$$= \frac{\cancel{2R} + 2\Delta R - \cancel{2R} - \Delta R}{2(2R+\Delta R)} = \frac{\Delta R}{2(2R+\Delta R)}$$

$$\Delta R << R \Rightarrow V_{out} \simeq \frac{\Delta R}{4R} V_{in}.$$

$$\frac{\Delta R}{R} = (GF)(\varepsilon)$$

$$\Rightarrow V_{out} = \frac{(GF)(\varepsilon)(N)}{4} V_{in} \qquad N: \text{\# active gages.}$$

Johnson (Thermal) Noise:

$$V'_{rms} = [4KT R(\Delta f)]^{1/2}$$

Δf = Bandwidth of scope

$k = 1.38 (10^{-23})$ J/K

R = Gage Resistance

$\Delta f = 100{,}000$??

Signal to Noise:

$$\frac{V'}{V} \simeq \frac{[4kTR\Delta f]^{1/2}}{[(GF\ \varepsilon\ N)/4]}$$

T = 300

R = 350

N = 2

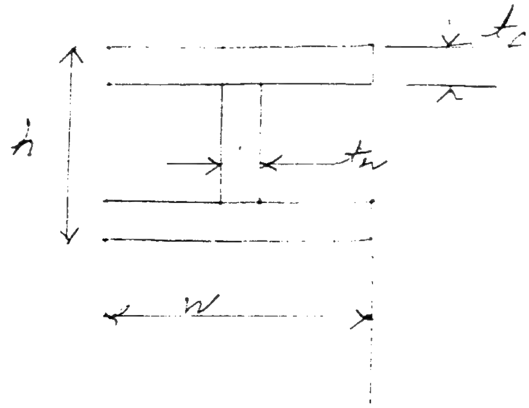
GF ≃ 2

$$SN = 1 \Rightarrow \varepsilon = .76 (10^{-6})$$

$$\Rightarrow \simeq 1 \mu\varepsilon \text{ measurable.}$$

FIGURE A-19

I of an I-Beam



$$M_{ass} = \rho L\left[2(t_f)(w) + t_w(h - 2t_f)\right]$$

$$I = \frac{1}{12} t_w (h - 2t_f)^3 + 2\left[\frac{1}{12} w t_f^3 + w t_f \left(h - \frac{t_f}{2}\right)^2\right]$$

$$= \frac{t_w}{12}(h - 2t_f)^3 + \frac{w t_f^3}{6} + 2 w t_f\left(h - \frac{t_f}{2}\right)^2$$

If $t_w = t_f = t$

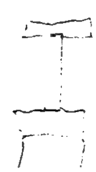
$$M_{ass} = \rho L t\left[2w + (h - 2t)\right]$$

$$I = \frac{t}{12}(h - 2t)^3 + \frac{w t^3}{6} + 2wt\left(h - \frac{t}{2}\right)^2$$

$\frac{h}{w} = R$ $\quad M_{ass} = \rho L t\left[2\frac{h}{R} + h - 2t\right]$

$$I = \frac{t}{12}(Rw - 2t)^3 + w\frac{t^3}{6} + 2wt\Big($$

Assume $t = .125$
$w = .375$
$h = .5$
$\Rightarrow I = 1.823(10^{-2})$



$\Rightarrow f_1 =$

FIGURE A-20

Natural Frequency of Fixed/Free Rectangular Beam

Harris, pg 7-15

$$f_1 = \frac{1}{2\pi} \frac{(1.875)^2}{L^2} \sqrt{\frac{E I g}{A \rho}}$$

rectangular: $\frac{I}{A} = \frac{\cancel{b} h^3}{12 \cancel{b} h} = \frac{h^2}{12}$

$$\Rightarrow f_1 = \frac{1}{2\pi} \frac{(1.875)^2}{L^2} \sqrt{\frac{E g}{\rho} \frac{h^2}{12}}$$

$g = 386 \text{ in}/s^2 \Rightarrow \boxed{f_1 = \frac{3.1734}{L^2} \sqrt{\frac{E h^2}{\rho}}}$

Example: Aluminum, $h = .312$, $L = 18''$, $\rho = .098$, $E = 10(10^6)$

$f_1 = 31$ Hz.

if $h = .5$ $f_1 = 49.5$ Hz.

$f_1 = 3.2(10^4) \frac{h}{L^2}$ $\quad f_1 = 1000$, $L = 18$ $\Rightarrow h = 10''$

Static Deflection: Own Weight.

$x = \frac{w L^4}{8 E I}$ $\quad w = \frac{\rho b h L}{L} = \rho b h$

$$x = \frac{\rho \cancel{b} \cancel{h} L^4 \, 12}{8 E \cancel{b} h^{\cancel{3}2}} = \frac{12 \rho L^4}{8 E h^2}$$

$$\boxed{x = 1.5 \frac{\rho L^4}{E h^2}}$$

	E/ρ
6AL 4V	103
6061 T6	102
316 SS	96.5
Graphite	139

FIGURE A-21

VARIABLE SHEET

St	Input	Name	Output	Unit	Comment
					************************************
					FUNDAMENTAL FREQUENCY OF FIXED-FREE BEAM: HARRIS PG. 7-15
					ALL IN IN-LBM SYSTEM
					************************************
					THIS CASE: GRAPHITE EPOXY
		f1	1078.0301		FUNDAMENTAL FREQUENCY
	1E7	E			YOUNG'S MODULUS (OR FLEX MODULUS)
		I	1.488		MOMENT OF INERTIA
	386	g			GRAVITY
		A	.6		AREA
	.05094	rho			DENSITY
	15	L			LENGTH
	2	h			HEIGHT
	.2	tf			FLANGE THICKNESS
	.125	tw			WEB THICKNESS
	1	w			WIDTH

RULE SHEET

```
S Rule
  A=2*tf*w+tw*(h-2*tf)
  I=(h-2*tf)^3*tw/12+tf^3*w/6+2*w*tf*(h-tf/2)^2
  f1=.55953*sqrt(E*I*g/(A*rho))/L^2
```

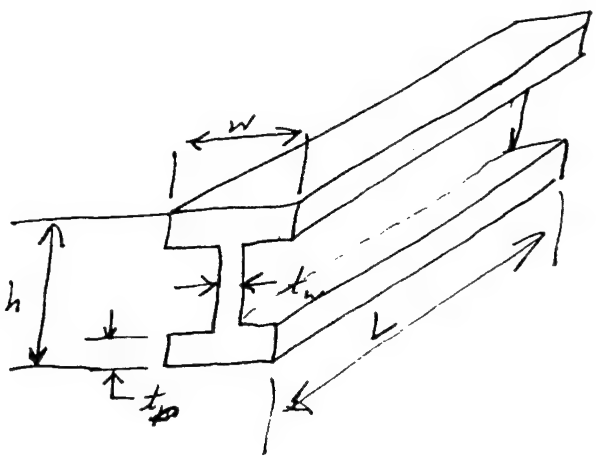
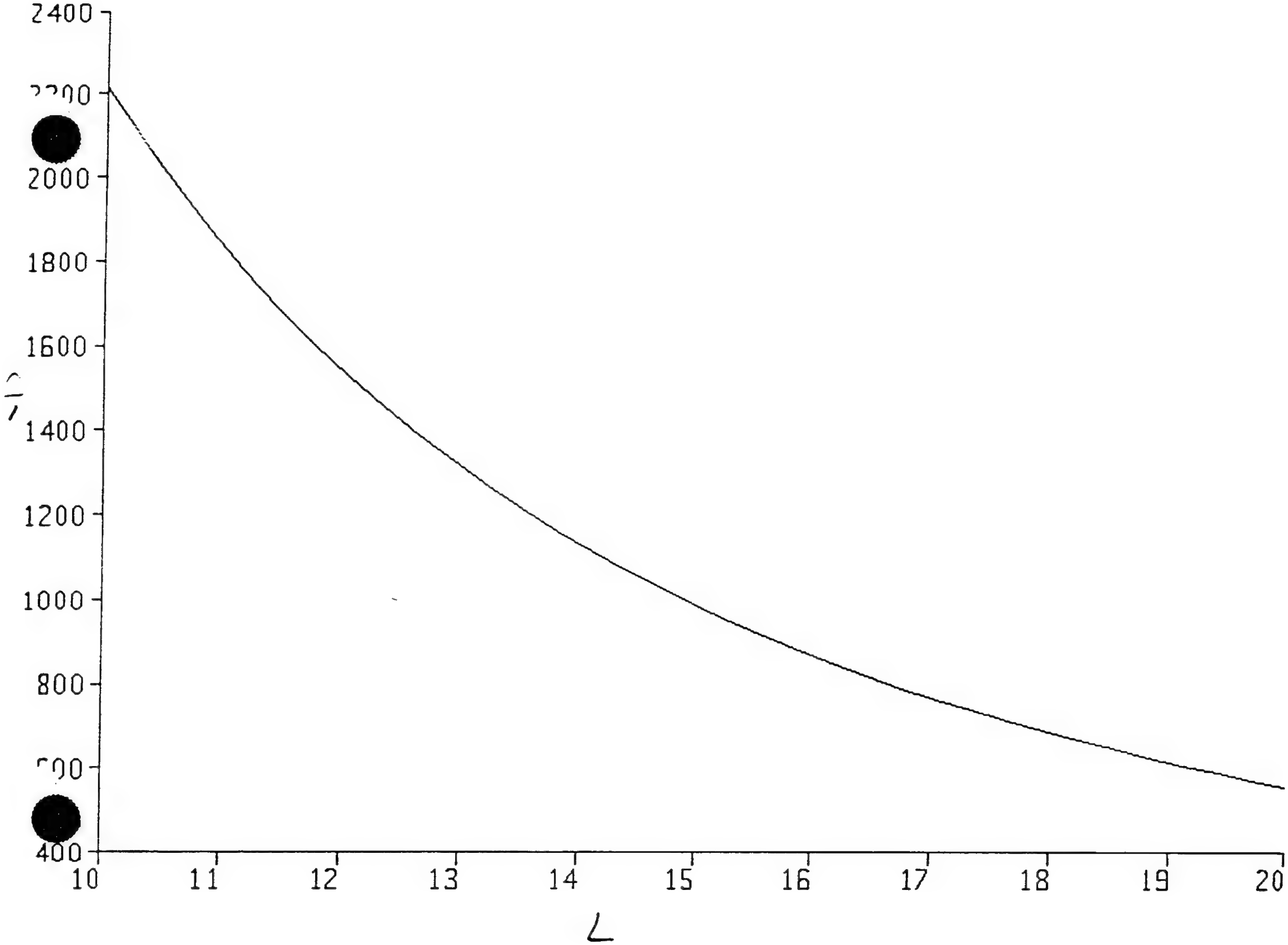
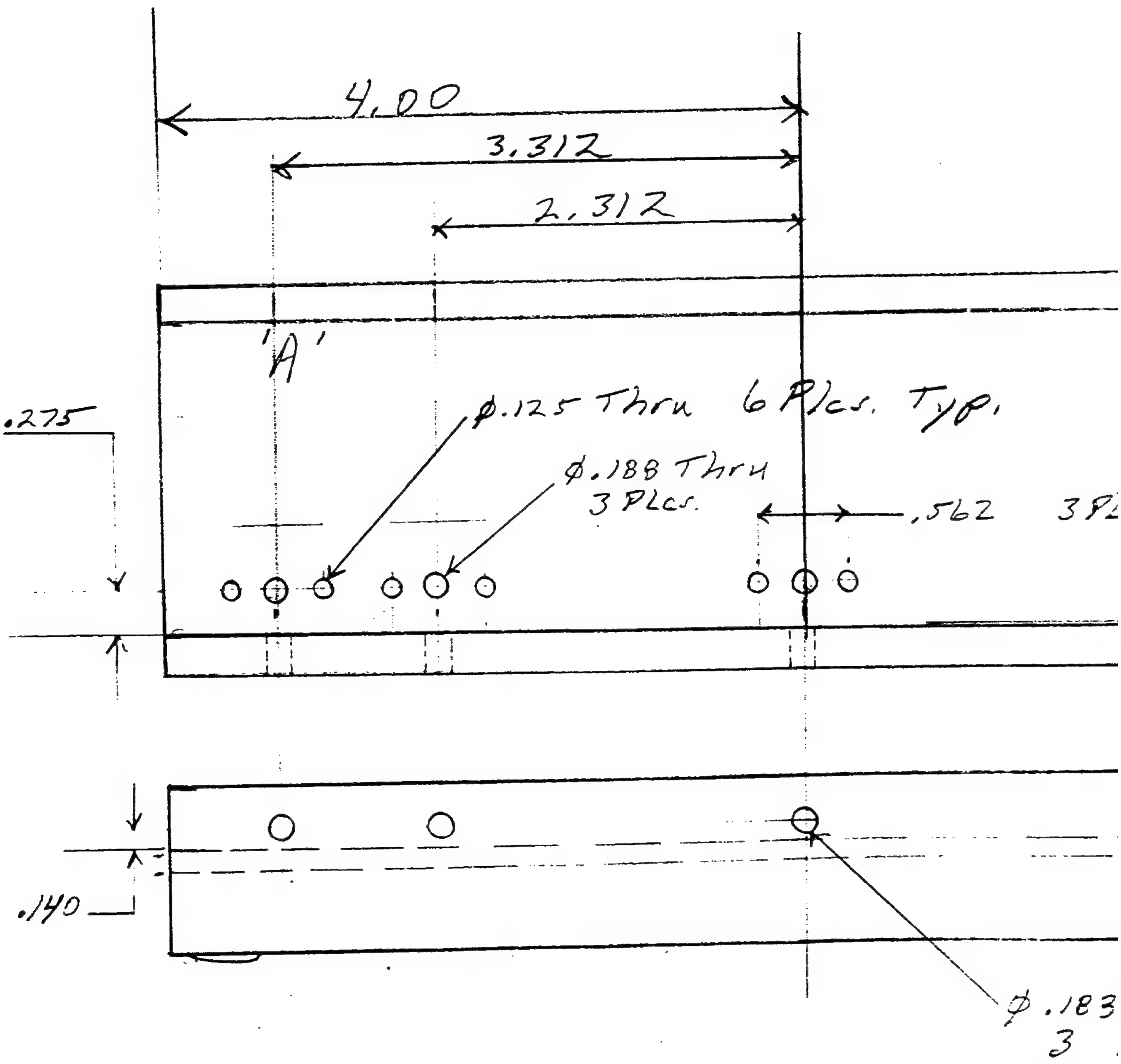


FIGURE A-22A



2400
2200
2000
1800
1600
1400
1200
1000
800
600
400
10
11
12
13
14
15
16
17
18
19
20
L

FIGURE A-22 B

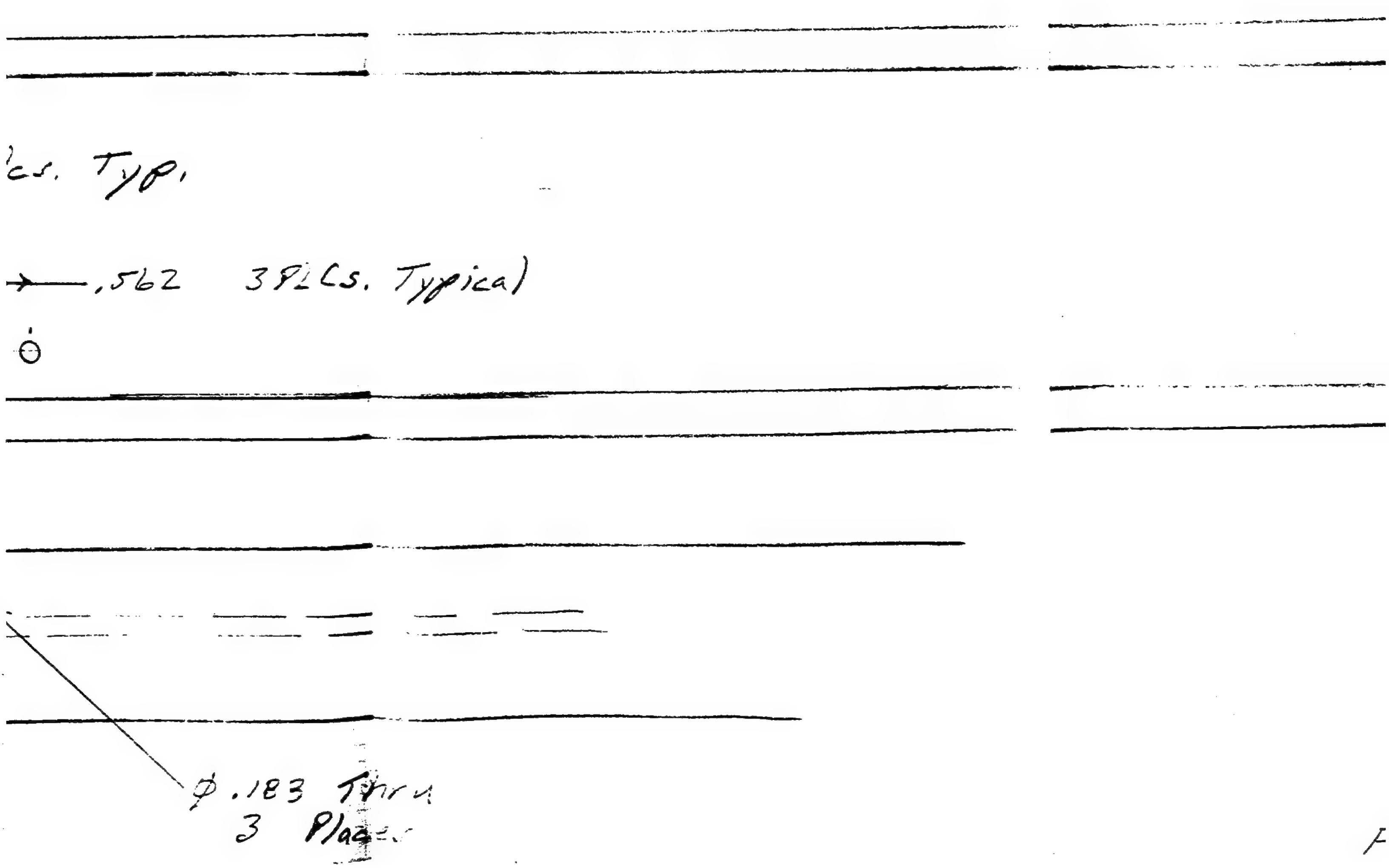


4.00
3.312
2.312
'A'
.275
ϕ.125 Thru 6 Plcs. Typ.
ϕ.188 Thru
3 Plcs.
.562
.140
ϕ.183
3

Drill Holes in Graphite
I Beam.

'A' orientation mark on Beam.

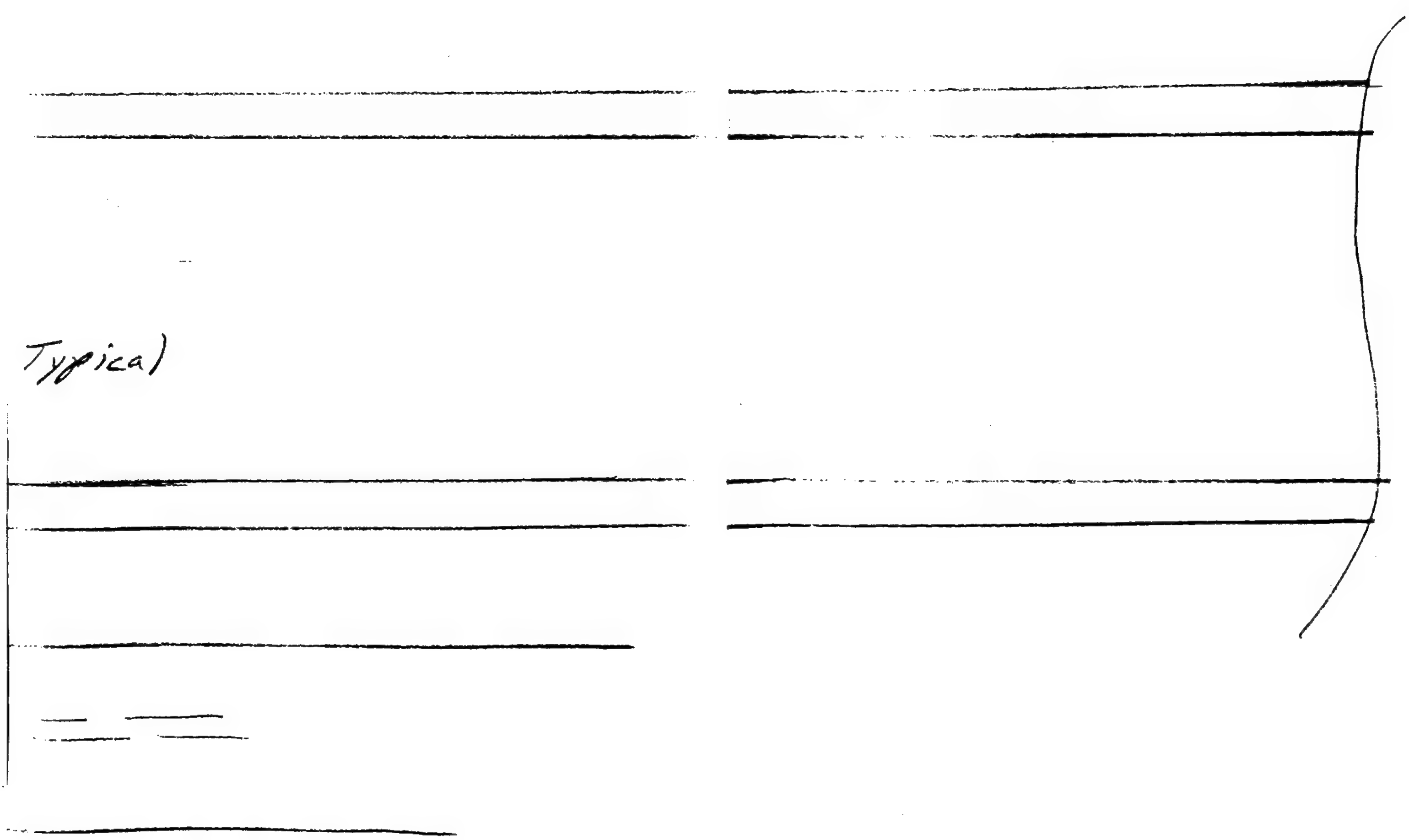
R. Daley
SC 87-6784-78



rill Holes in Graphite
- Beam.

' Orientation mark on Beam

R. Daley
SC 87-6784-78



ru

FIGURE A-23

Purpose of Ball Joints

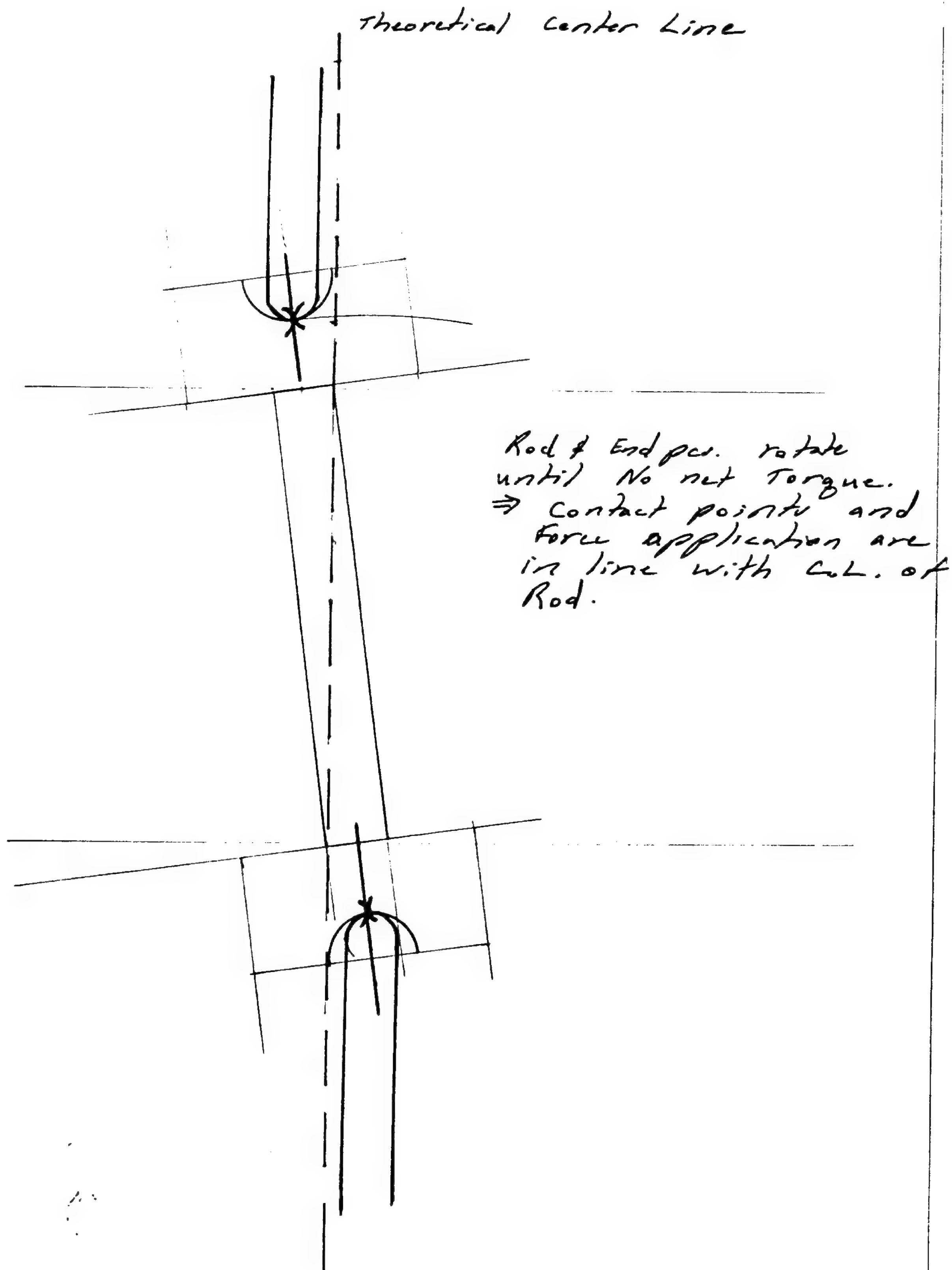


FIGURE A-24

Spherical Ball in Spherical Socket

Roarke, Pg. 650

$$\sigma_{max} = .616 \left[\frac{PE^2}{K^2}\right]^{1/3} \qquad K = \frac{D_1 D_2}{D_1 - D_2}$$

$D_1 - D_2$ controlled by Tolerances, assume $D_1 - D_2 = \delta$

$D_1 \simeq D_2 \Rightarrow D_1 D_2 \simeq D^2$

$$\Rightarrow K = \frac{D^2}{\delta} \qquad K^2 = \frac{D^4}{\delta^2}$$

$$\left(\frac{\sigma_{max}}{.616}\right)^3 \frac{D^4}{\delta^2} = PE^2$$

$$D_{req} = \left[\frac{PE^2 \delta^2 (.616)^3}{\sigma_{max}^3}\right]^{.25}$$

$$\boxed{D_{req} = (.6953)\left[\frac{PE^2\delta^2}{\sigma_{max}^3}\right]^{.25}}$$

Example: $E = 28E^6 \quad \delta = .010 \quad \sigma_{max} = 40,000$

$P = 528$ lb.

$\Rightarrow D_{req} = .6235$

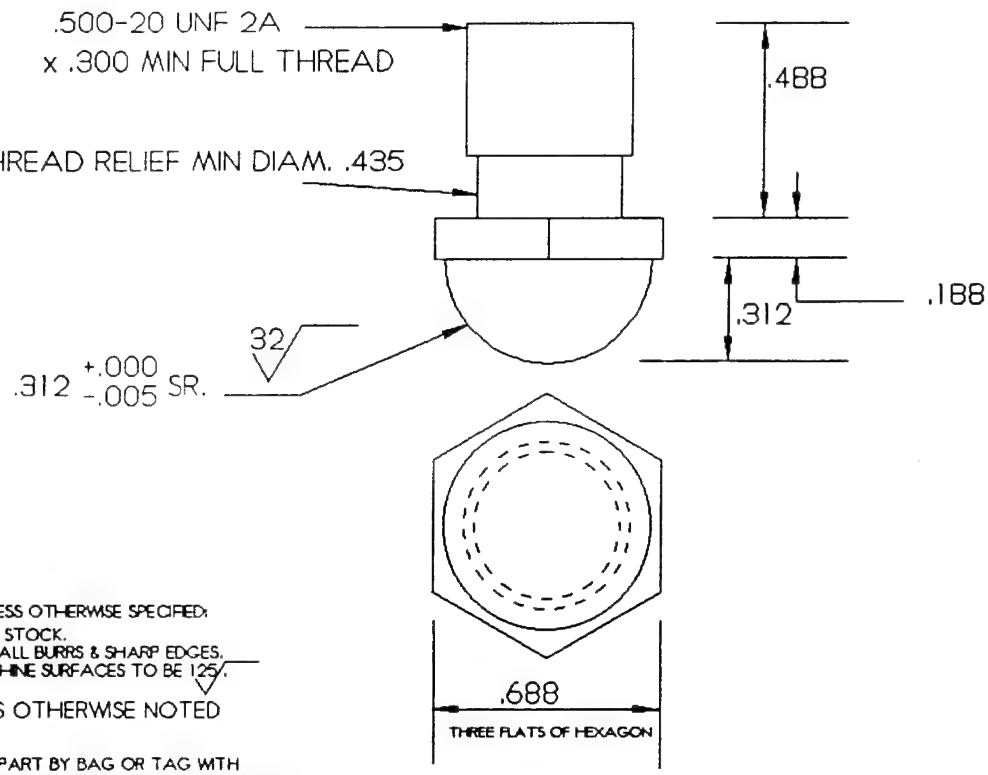
FIGURE A-25

NUMBER	TITLE	FILENAME	QUANTITY REQ.
6784RD1	LOAD BUTTON	BUTTON.FCD	2
6784RD2	BUTTON SOCKET	SOCKET.FCD	2
6784RD3	JAM NUT	JAMNUT.FCD	4
6784RD4	LVDT BLOCK	LVDTBLOC.FCD	1
6784RD5	BUSHING GUSSETT	GUSSETT.FCD	1
6784RD6	TOP PLATE	TOPLATE.FCD	1
6784RD7	LEFT SIDE PLATE	LSPLATE.FCD	1
6784RD8	RIGHT SIDE PLATE	RSPLATE.FCD	1
6784RD9	BACK PLATE	BACKPLAT.FCD	1
6784RD10	THREADED ROD	TROD.FCD	3
6784RD11	BASE PLATE	BPLATE.FCD	1
6784RD12	ROD CHUCK	RODCHUCK.FCD	2 EA. X 4 DASH NO.= 8
6784RD13	LEVER PIVOT	PIVOT.FCD	1
6784RD14	SPACER BLOCK	SPACERBL.FCD	1 EA. X 3 DASH NO. =3
6784RD15	BEARING BLOCK	BEARINGB.FCD	3
6784RD16	AXLE	AXLE.FCD	3
B8-1	TEFLON BEARING	.252 O.D. .126 I.D. .125 LONG	1
6784RD17	LEVER BEAM		1
18	Table Top		
19	Level Adjuster	Leveladj.FCD	1

FIGURE A-26

Test Apparatus Drawings

APPLICATION		REVISIONS			
NEXT ASSY	USED ON	LTR	DESCRIPTION	DATE	APPROVED



NOTES, UNLESS OTHERWISE SPECIFIED:

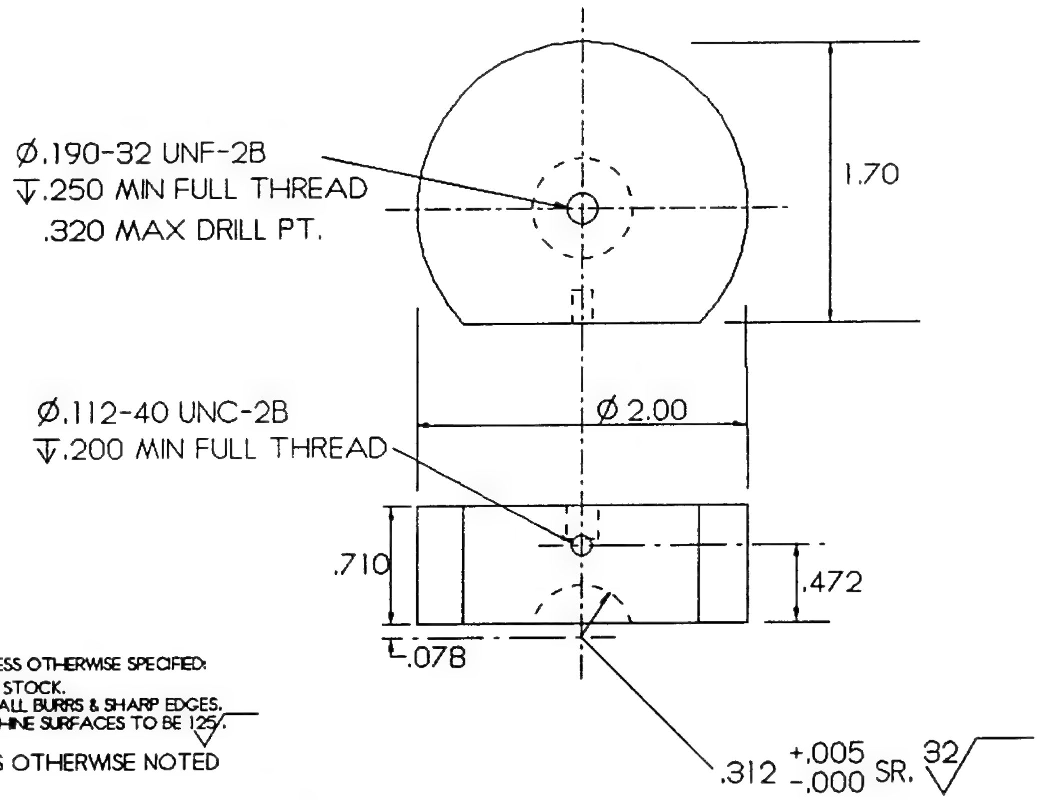
1. FINISH AS STOCK.
   REMOVE ALL BURRS & SHARP EDGES.
   ALL MACHINE SURFACES TO BE 125
   UNLESS OTHERWISE NOTED
2. IDENTIFY PART BY BAG OR TAG WITH PART NUMBER AND REVISION LETTER LEGIBLY PER MIL-STD-130 USING .12 INCH HIGH CHARACTERS.
3. FINISH: AUTOCATALYTIC NICKEL/PTFE COATING, SINTERED AT 750°F .0002 ± .0001 COATING THICKNESS. DIMENSIONS APPLY AFTER COATING.

   RECOMMENDED SOURCE OF COATING: LINCOLN PLATING
   LINCOLN, NEBRASKA (402) 275-3671

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES TOLERANCES: ANGULAR ± 2 PLACE DECIMALS ± .03 3 PLACE DECIMALS ± .010	DRAWN	Rick Daley	EDO CORPORATION — ELECTRO ACOUSTIC DIVISION
	CHECKED		
	STRESS	Rick Daley	DRAWING TITLE: LOAD BUTTON
DO NOT SCALE THIS DRAWING	ENGRG	Rick Daley	
MATERIAL: STAINLESS STEEL AISI TYPE 316 OR 316L	RELEASE DATE		SIZE: A — CODE IDENT NO.: 24338 — DWG NO.: 6784RD1
	APPROVED		
	SC: 87-6784-78		SCALE: NONE — SHEET: 1 OF 1

FILE: BUTTON.FCD

APPLICATION		REVISIONS			
NEXT ASSY	USED ON	LTR	DESCRIPTION	DATE	APPROVED



NOTES, UNLESS OTHERWISE SPECIFIED:

1. FINISH AS STOCK.
   REMOVE ALL BURRS & SHARP EDGES.
   ALL MACHINE SURFACES TO BE 125
   UNLESS OTHERWISE NOTED
2. IDENTIFY PART BY BAG OR TAG WITH PART NUMBER AND REVISION LETTER LEGIBLY PER MIL-STD-130 USING .12 INCH HIGH CHARACTERS.
3. FINISH: AUTOCATALYTIC NICKEL/PTFE COATING, SINTERED AT 750°F .0002 ± .0001 COATING THICKNESS. DIMENSIONS APPLY AFTER COATING.

   RECOMMENDED SOURCE OF COATING: LINCOLN PLATING
   LINCOLN, NEBRASKA (402) 275-3671

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES TOLERANCES: ANGULAR ± 2 PLACE DECIMALS ± .03 3 PLACE DECIMALS ± .010	DRAWN	Rick Daley
	CHECKED	
	STRESS	Rick Daley
DO NOT SCALE THIS DRAWING	ENGRG	Rick Daley
MATERIAL: STAINLESS STEEL AISI TYPE 316 OR 316L	RELEASE DATE	
	APPROVED	
	SC: 87-67B4-78	

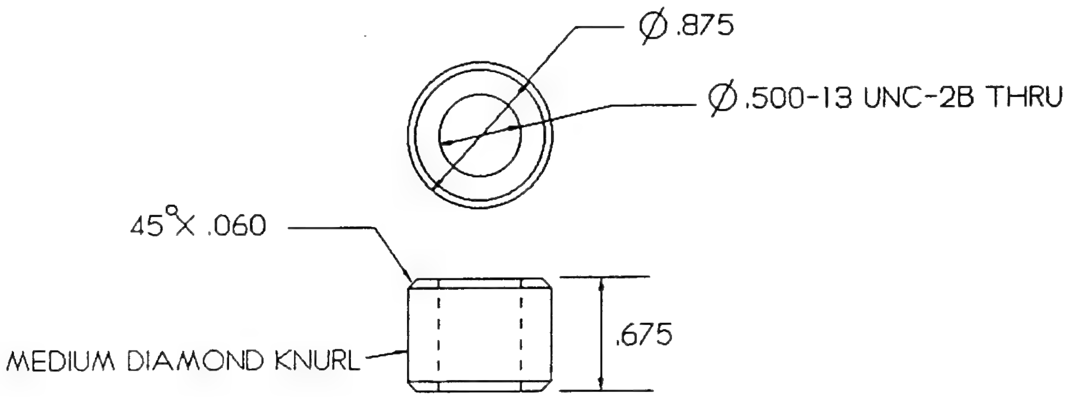
EDO CORPORATION — ELECTRO ACOUSTIC DIVISION

DRAWING TITLE: BUTTON SOCKET

SIZE	CODE IDENT NO.	DWG NO.
A	24338	67B4RD2
SCALE: NONE		SHEET: 1 OF 1

FILE: SOCKET.FCD

APPLICATION		REVISIONS			
NEXT ASSY	USED ON	LTR	DESCRIPTION	DATE	APPROVED

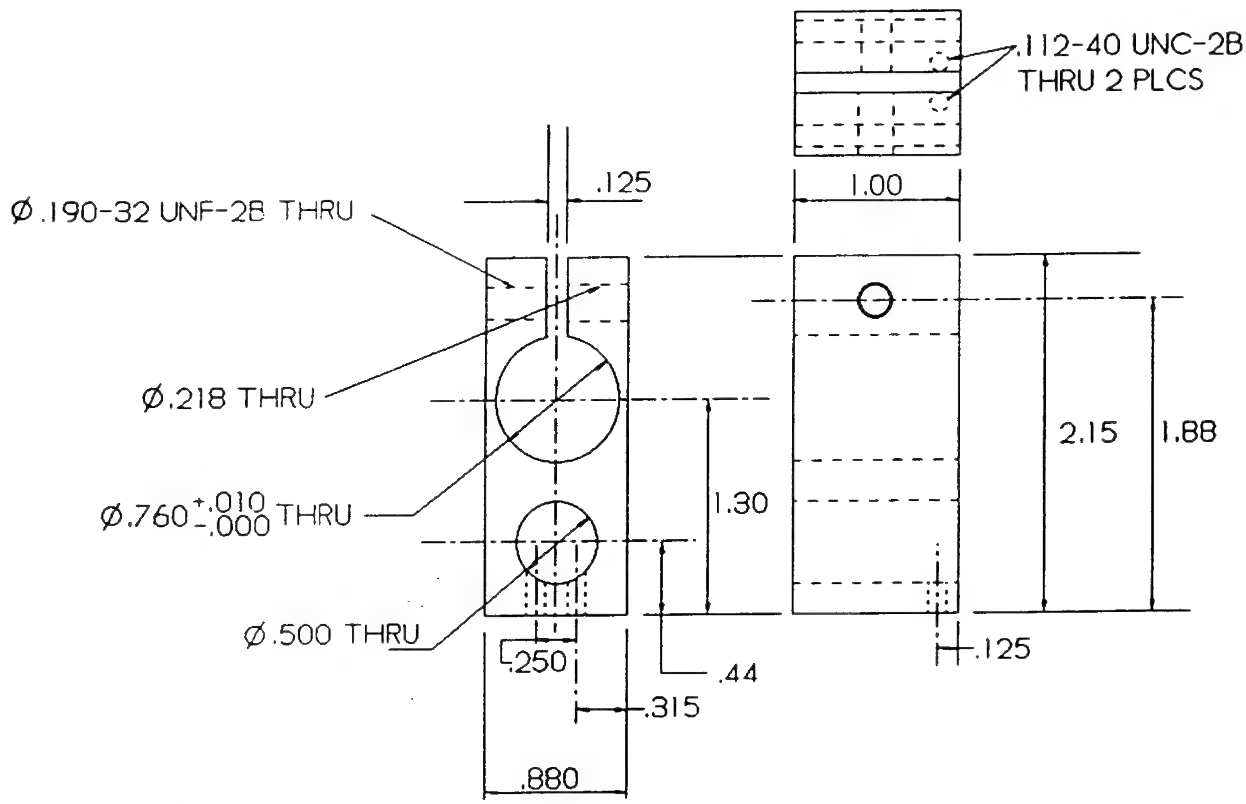


NOTES, UNLESS OTHERWISE SPECIFIED:

1. FINISH AS STOCK.
   REMOVE ALL BURRS & SHARP EDGES.
   ALL MACHINE SURFACES TO BE 125√
   UNLESS OTHERWISE NOTED
2. IDENTIFY PART BY BAG OR TAG WITH
   PART NUMBER AND REVISION LETTER LEGIBLY
   PER MIL-STD-130 USING .12 INCH HIGH CHARACTERS.
3. FINISH: AUTOCATALYTIC NICKEL/PTFE COATING, SINTERED AT 750°F
   .0002 ±.0001 COATING THICKNESS. DIMENSIONS APPLY AFTER COATING.
   RECOMMENDED SOURCE OF COATING: LINCOLN PLATING
   LINCOLN, NEBRASKA (402) 275-3671

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES TOLERANCES: ANGULAR ± 2 PLACE DECIMALS ± .03 3 PLACE DECIMALS ± .010	DRAWN	Rick Daley	EDO CORPORATION	ELECTRO ACOUSTIC DIVISION
	CHECKED			
	STRESS	Rick Daley	DRAWING TITLE: JAM NUT	
DO NOT SCALE THIS DRAWING	ENGRG	Rick Daley		
MATERIAL: STAINLESS STEEL AISI TYPE 316 OR 316L	RELEASE DATE			
	APPROVED		SIZE A / CODE IDENT NO. 24338	DWG NO. 6784RD3
	SC: 87-6784-78		SCALE: NONE	SHEET: 1 OF 1

FILE: JAMNUT.FCD



NOTES, UNLESS OTHERWISE SPECIFIED:

1. FINISH AS STOCK.
   REMOVE ALL BURRS & SHARP EDGES.
   ALL MACHINE SURFACES TO BE 125
   UNLESS OTHERWISE NOTED
2. IDENTIFY PART BY BAG OR TAG WITH
   PART NUMBER AND REVISION LETTER LEGIBLY
   PER MIL-STD-130 USING .12 INCH HIGH CHARACTERS.

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES TOLERANCES: ANGULAR ± 2 PLACE DECIMALS ± .03 3 PLACE DECIMALS ± .010	DRAWN	Rick Daley	EDO CORPORATION ELECTRO ACOUSTIC DIVISION
	CHECKED		
	STRESS	Rick Daley	DRAWING TITLE:
DO NOT SCALE THIS DRAWING	ENGRG	Rick Daley	LVDT BLOCK
MATERIAL: STAINLESS STEEL AISI TYPE 316 OR 316L	RELEASE DATE		SIZE A · CODE IDENT NO. 24338 · DWG NO. 67B4RD4
	APPROVED		
	SC: 87-6784-78		SCALE: NONE · REVISION A · SHEET: 1 OF 1

FILE: LVDTBLOC.FCD

DWG NO	B

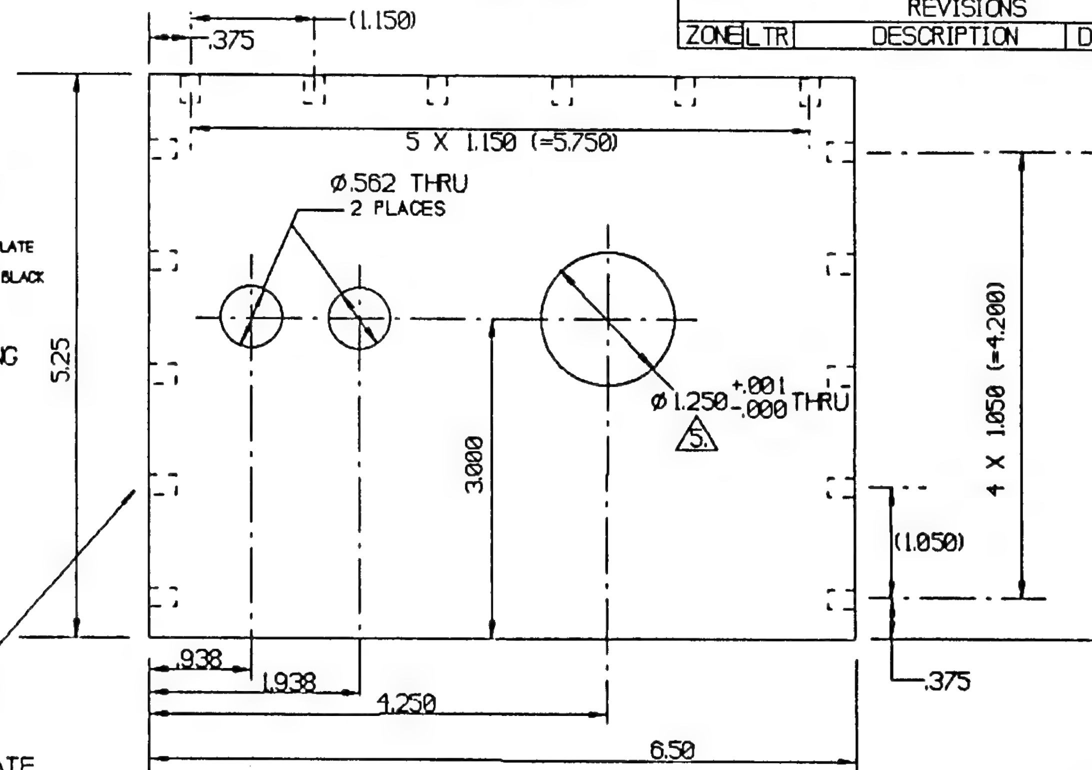
REVISIONS

ZONE	LTR	DESCRIPTION	DATE	APPROVED

NOTES. UNLESS OTHERWISE SPECIFIED

1. FINISH AS STOCK.
   REMOVE ALL BURRS AND SHARP EDGES.
   ALL MACHINED SURFACES TO BE 125
2. METAL STAMP PART NUMBER AND REVISION LETTER PERMANENTLY AND LEGIBLY PER MIL-STD-130 USING .12 INCH HIGH CHARACTERS. PART NUMBER IS SAME AS DRAWING NUMBER.
3. MATERIAL: ALUM. ALLOY 6061-T6 .750 THICK PLATE
4. FINISH: HARD ANODIZE. .002 THICKNESS. COLOR: BLACK

5. BUSHING HOLE FOR USE WITH BERG LMB-4SS BEARING



HELICOILS: Ø.190-24 UNC-2B
X .285 NOMINAL LENGTH
16 PLACES ON MIDLINE OF PLATE

ITEM	-1	-2	-3	-4	DWG SIZE	PART NUMBER	DESCRIPTION	VENDOR / MATERIAL SPEC.	CAGE CODE NO.

PARTS LIST OR LIST OF MATERIALS

DIMENSIONSING AND TOLERANCING PER ANSI Y14.5M-1982 UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES

TOLERANCES:
2 PLACE DECIMAL ±.03
3 PLACE DECIMAL ±.010

DRAWN BY	DATE
R. Daley	
ENGINEER	
R. Daley	

NEXT ASSY	USED ON
APPLICATION	

INTERPRET DRAWING IN ACCORDANCE WITH DOD-D-1000

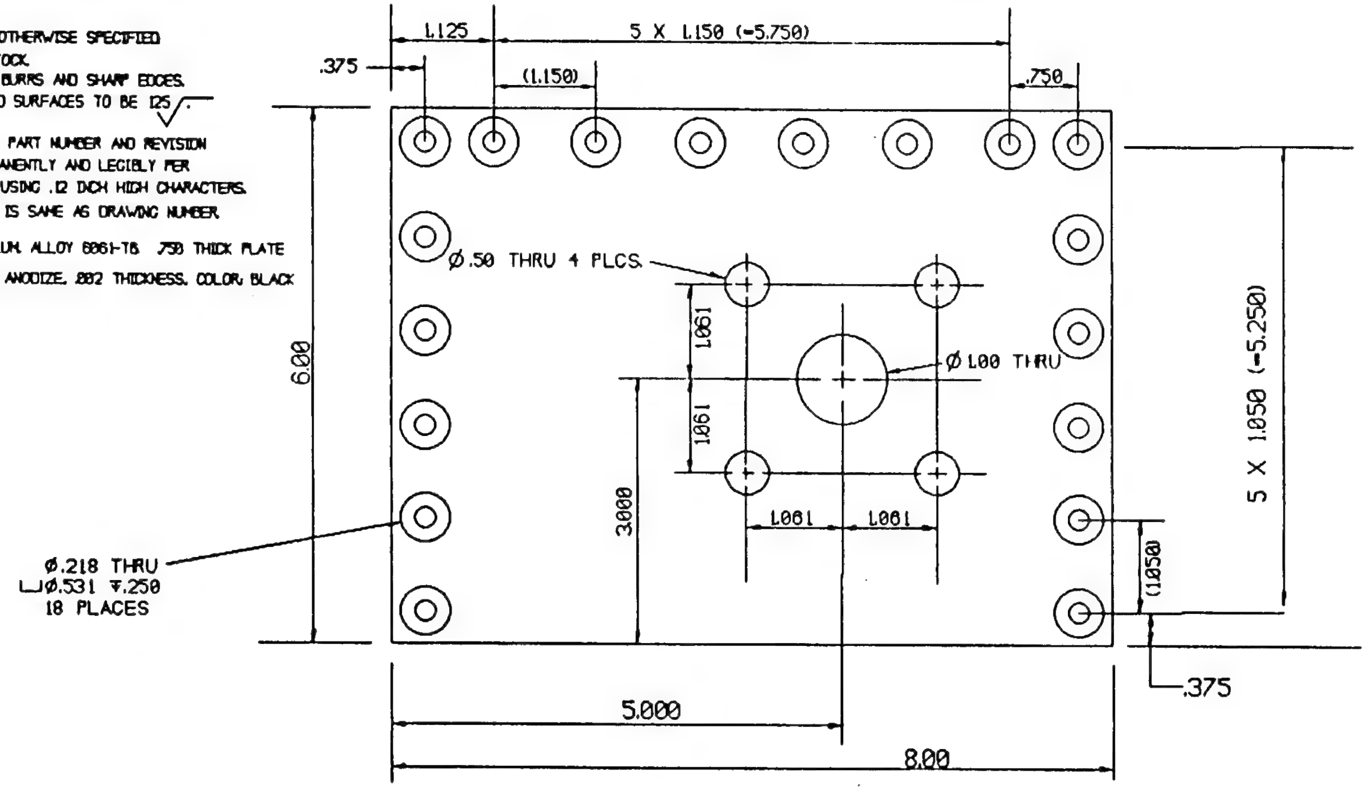
EDO CORPORATION ELECTRO ACOUSTIC DIVISION 2645 SOUTH 300 WEST SALT LAKE CITY, UTAH 84115

BUSHING GUSSET

SIZE	CAGE	DWG NO.	REV
B	24338	6784RD5	
SCALE: NONE		SHEET 1 OF 1	

FILE: GUSSETT.FCD

NOTES. UNLESS OTHERWISE SPECIFIED
1. FINISH AS STOCK.
   REMOVE ALL BURRS AND SHARP EDGES.
   ALL MACHINED SURFACES TO BE 125 $\sqrt{}$.
2. METAL STAMP PART NUMBER AND REVISION LETTER PERMANENTLY AND LEGIBLY PER MIL-STD-130 USING .12 INCH HIGH CHARACTERS. PART NUMBER IS SAME AS DRAWING NUMBER.
3. MATERIAL: ALUM. ALLOY 6061-T6 .750 THICK PLATE
4. FINISH: HARD ANODIZE, .002 THICKNESS, COLOR: BLACK

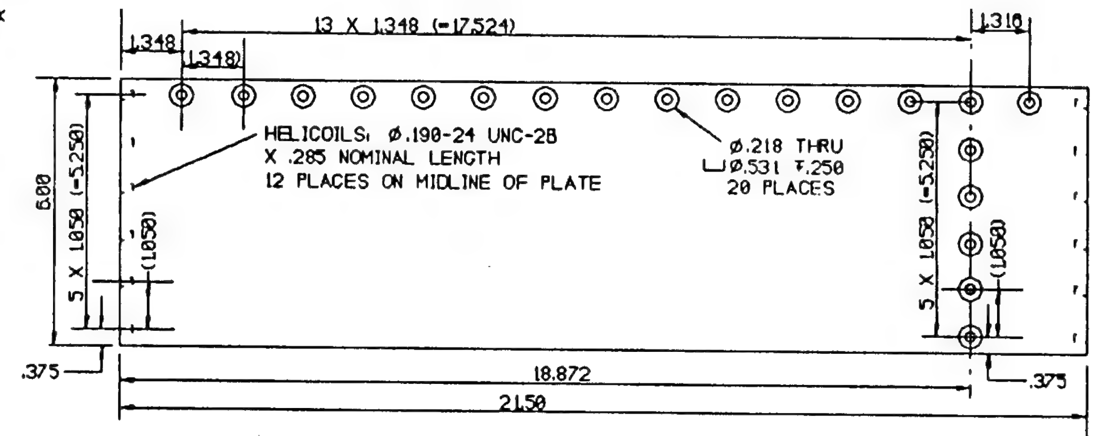


		DIMENSIONING AND TOLERANCING PER ANSI Y14.5M-1982 UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES		EDO CORPORATION ELECTRO ACOUSTIC DIVISION 2645 SOUTH 300 WEST SALT LAKE CITY, UTAH 84115	
		TOLERANCES: 2 PLACE DECIMAL ±.03 3 PLACE DECIMAL ±.010	DRAWN BY R. Daley / DATE	TOP PLATE	
NEXT ASSY	USED ON			SIZE B / CAGE 24338 / DWG NO. 6784RD6	REV
APPLICATION		INTERPRET DRAWING IN ACCORDANCE WITH DOD-D-1000	ENGINEER R. Daley	SCALE NONE	SHEET 1 OF 1

FILE: TOPLATE.FCD

NOTES. UNLESS OTHERWISE SPECIFIED

1. FINISH AS STOCK.
   REMOVE ALL BURRS AND SHARP EDGES.
   ALL MACHINED SURFACES TO BE 125√
2. METAL STAMP PART NUMBER AND REVISION LETTER PERMANENTLY AND LEGIBLY PER MIL-STD-130 USING .12 INCH HIGH CHARACTERS. PART NUMBER IS SAME AS DRAWING NUMBER.
3. MATERIAL: ALUM. ALLOY 6061-T6 .750 THICK PLATE
4. FINISH: HARD ANODIZE. .002 THICKNESS. COLOR: BLACK

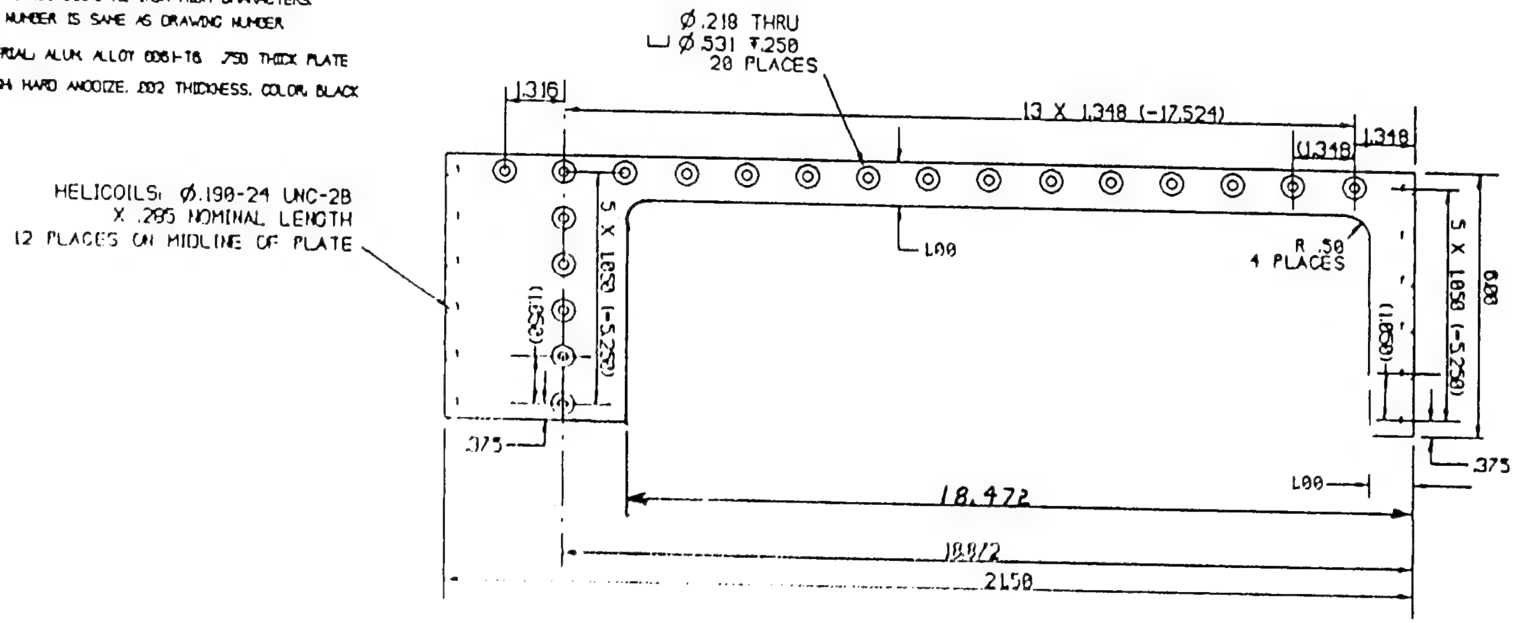


DIMENSIONING AND TOLERANCING PER ANSI Y14.5M-1982 UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES		EDO CORPORATION	ELECTRO ACOUSTIC DIVISION	2645 SOUTH 300 WEST SALT LAKE CITY, UTAH 84115
TOLERANCES: 2 PLACE DECIMAL ±.03 3 PLACE DECIMAL ±.010	DRAWN BY R. Daley / DATE	LEFT SIDE PLATE		
NEXT ASSY / USED ON — APPLICATION		SIZE B	CAGE 24338	DWG NO. 6784RD7 / REV
INTERPRET DRAWING IN ACCORDANCE WITH DOD-D-1000	ENGINEER R. Daley	SCALE NONE		SHEET 1 OF 1

FILE: LSPLATE.FCD

NOTES UNLESS OTHERWISE SPECIFIED

1. FINISH AS STOCK.
   REMOVE ALL BURRS AND SHARP EDGES.
   ALL MACHINED SURFACES TO BE 125 √
2. METAL STAMP PART NUMBER AND REVISION LETTER PERMANENTLY AND LEGIBLY PER MIL-STD-130 USING .12 INCH HIGH CHARACTERS. PART NUMBER IS SAME AS DRAWING NUMBER
3. MATERIAL: ALUM. ALLOY 6061-T6 .750 THICK PLATE
4. FINISH HARD ANODIZE .002 THICKNESS, COLOR: BLACK

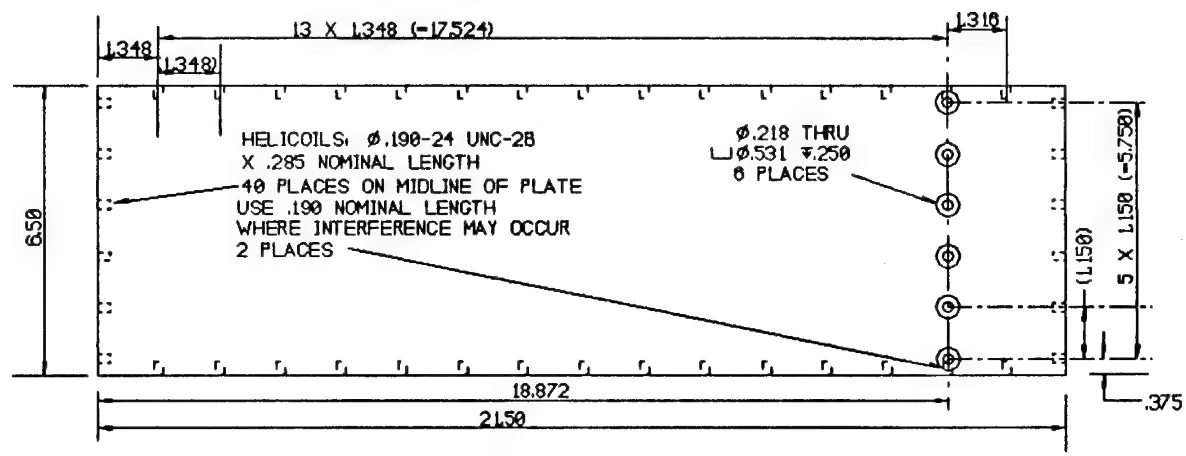


		DIMENSIONING AND TOLERANCING PER ANSI Y14.5M-1982 UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES		EDO CORPORATION ELECTRO ACOUSTIC DIVISION 2645 SOUTH 300 WEST SALT LAKE CITY, UTAH 84115	
		TOLERANCES: 2 PLACE DECIMAL ±.03 3 PLACE DECIMAL ±.010	DRAWN BY R. Daley	DATE	RIGHT SIDE PLATE
NEXT ASSY	USED ON		ENGINEER R. Daley	SIZE B / CAGE 21338 / DWG NO. 6784RD8 / REV	
APPLICATION		INTERPRET DRAWING IN ACCORDANCE WITH DOD-D-1000		SCALE NONE	SHEET 1 OF 1

FILE: RSPLATE.FCD

NOTES. UNLESS OTHERWISE SPECIFIED

1. FINISH AS STOCK.
   REMOVE ALL BURRS AND SHARP EDGES.
   ALL MACHINED SURFACES TO BE 125 √
2. METAL STAMP PART NUMBER AND REVISION LETTER PERMANENTLY AND LEGIBLY PER MIL-STD-130 USING .12 INCH HIGH CHARACTERS. PART NUMBER IS SAME AS DRAWING NUMBER.
3. MATERIAL: ALUM. ALLOY 6061-T6 .750 THICK PLATE
4. FINISH: HARD ANODIZE. .002 THICKNESS. COLOR: BLACK



NEXT ASSY	USED ON	DIMENSIONSING AND TOLERANCING PER ANSI Y14.5M-1982 UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES
APPLICATION		TOLERANCES: 2 PLACE DECIMAL ±.03 3 PLACE DECIMAL ±.010
		INTERPRET DRAWING IN ACCORDANCE WITH DOD-D-1000

DRAWN BY: R. Daley | DATE: | ENGINEER: R. Daley

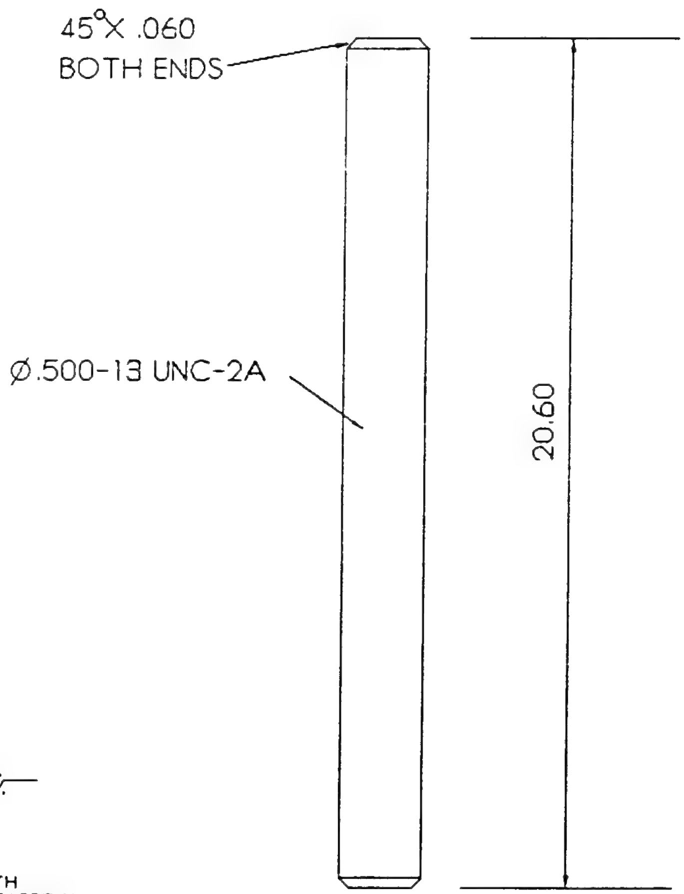
EDO CORPORATION — ELECTRO ACOUSTIC DIVISION — 2645 SOUTH 300 WEST SALT LAKE CITY, UTAH 84115

BACK PLATE

SIZE	CAGE	DWG NO.	REV
B	24338	6784RD9	
SCALE NONE		SHEET 1 OF 1	

FILE: BACKPLAT.FCD

APPLICATION		REVISIONS			
NEXT ASSY	USED ON	LTR	DESCRIPTION	DATE	APPROVED

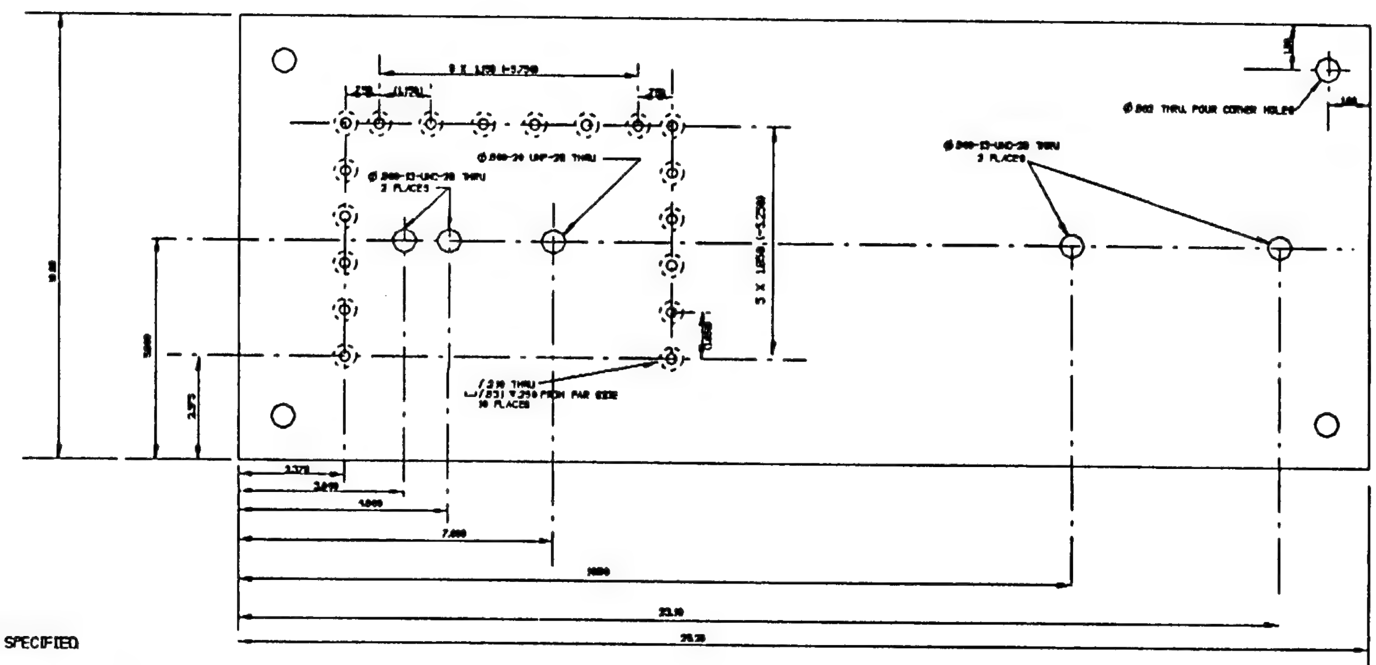


NOTES, UNLESS OTHERWISE SPECIFIED:

1. FINISH AS STOCK.
   REMOVE ALL BURRS & SHARP EDGES.
   ALL MACHINE SURFACES TO BE 125√.
   UNLESS OTHERWISE NOTED
2. IDENTIFY PART BY BAG OR TAG WITH
   PART NUMBER AND REVISION LETTER LEGIBLY
   PER MIL-STD-130 USING .12 INCH HIGH CHARACTERS.

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES TOLERANCES: ANGULAR ± 2 PLACE DECIMALS ± .03 3 PLACE DECIMALS ± .010	DRAWN	Rick Daley	EDO CORPORATION	ELECTRO ACOUSTIC DIVISION	
	CHECKED				
	STRESS	Rick Daley	DRAWING TITLE: THREADED ROD		
DO NOT SCALE THIS DRAWING	ENGRG	Rick Daley			
MATERIAL: STAINLESS STEEL AISI TYPE 316 OR 316L	RELEASE DATE				
	APPROVED		SIZE A	CODE IDENT NO. 24338	DWG NO. 6784RD10
	SC: 87-6784-78		SCALE: NONE		SHEET: 1 OF 1

FILE: TROD.FCD



NOTES. UNLESS OTHERWISE SPECIFIED.
1 FINISH AS STOCK.
REMOVE ALL BURRS AND SHARP EDGES.
ALL MACHINED SURFACES TO BE 125 .

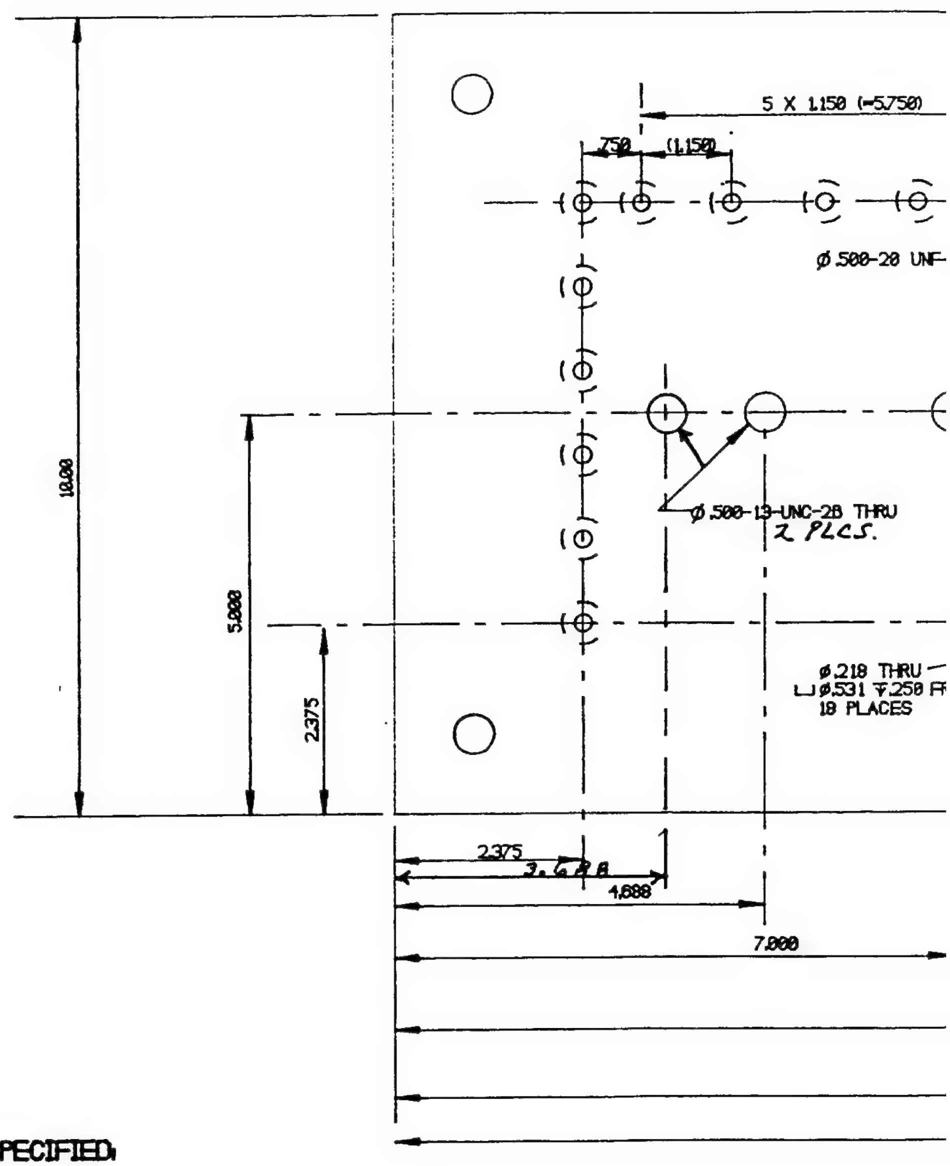
2 METAL STAMP PART NUMBER AND REVISION LETTER PERMANENTLY AND LEGIBLY PER MIL-STD-130 USING .12 INCH HIGH CHARACTERS. PART NUMBER IS SAME AS DRAWING NUMBER.

3 MATERIAL: ALUM. ALLOY 6061-T6 .750 THICK PLATE

4. FINISH: HARD ANODIZE .002 THICKNESS. COLOR: BLACK

		DIMENSIONSING AND TOLERANCING PER ANSI Y14.5M-1982 UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES		EDO CORPORATION	ELECTRO ACOUSTIC DIVISION	2645 SOUTH 300 WEST SALT LAKE CITY, UTAH 84115
		TOLERANCES: 2 PLACE DECIMAL .03 3 PLACE DECIMAL .010	DRAWN BY R. Daley	BASE PLATE		
			DATE	SIZE B	CAGE 24338	DWG NO. 6784RD11 REV
NEXT ASSY	USED ON	INTERPRET DRAWING IN ACCORDANCE WITH DOD-D-1000	ENGINEER R. Daley	SCALE NONE		SHEET 1 OF 1
APPLICATION						

FILE: BPLATE.FCD



NOTES, UNLESS OTHERWISE SPECIFIED:

1. FINISH AS STOCK.
   REMOVE ALL BURRS AND SHARP EDGES.
   ALL MACHINED SURFACES TO BE 125 .

2. METAL STAMP PART NUMBER AND REVISION LETTER PERMANENTLY AND LEGIBLY PER MIL-STD-130 USING .12 INCH HIGH CHARACTERS.
   PART NUMBER IS SAME AS DRAWING NUMBER.

3. MATERIAL: ALUM. ALLOY 6061-T6. .750 THICK PLATE

4. FINISH: HARD ANODIZE, .002 THICKNESS, COLOR: BLACK

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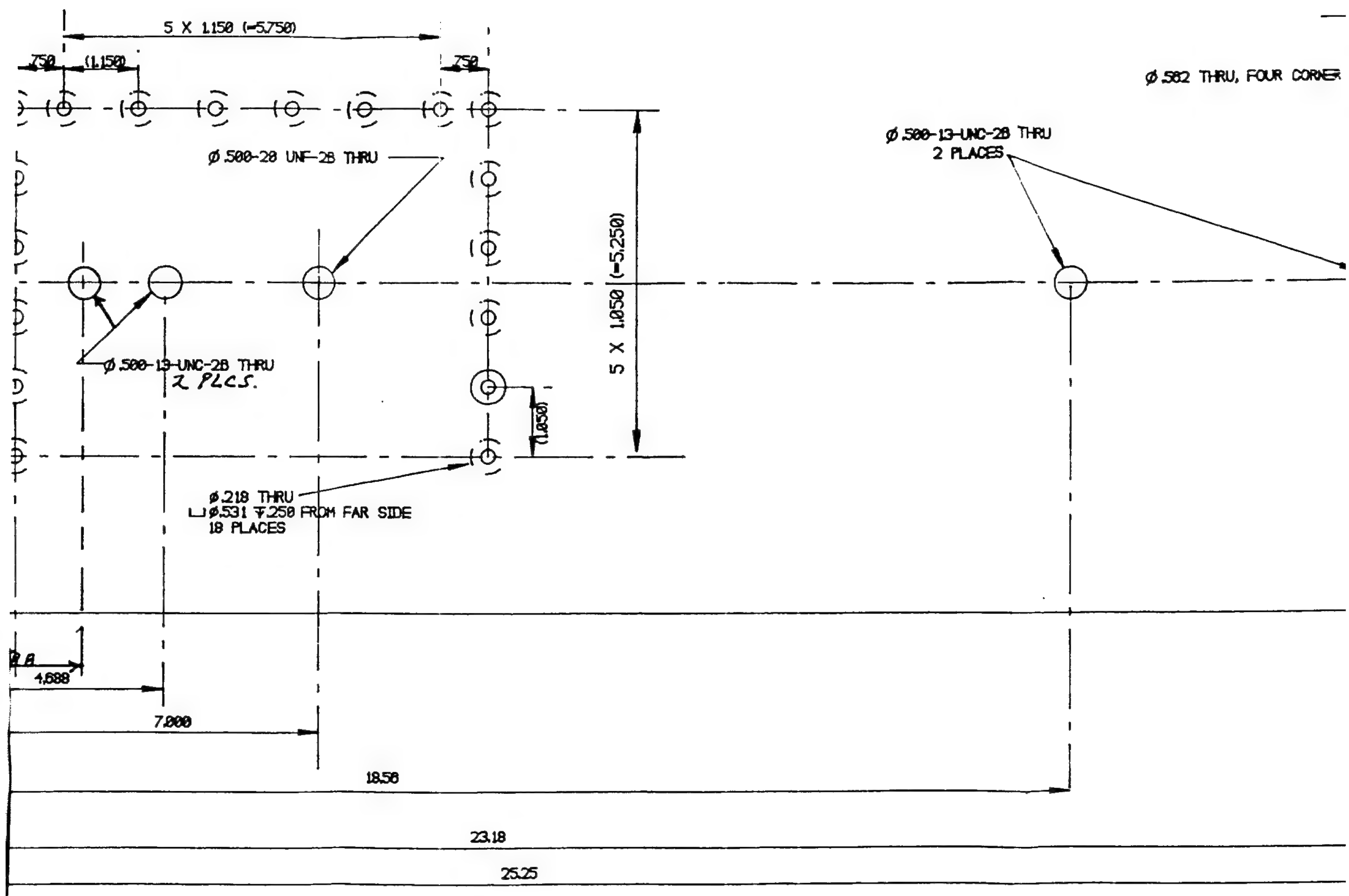
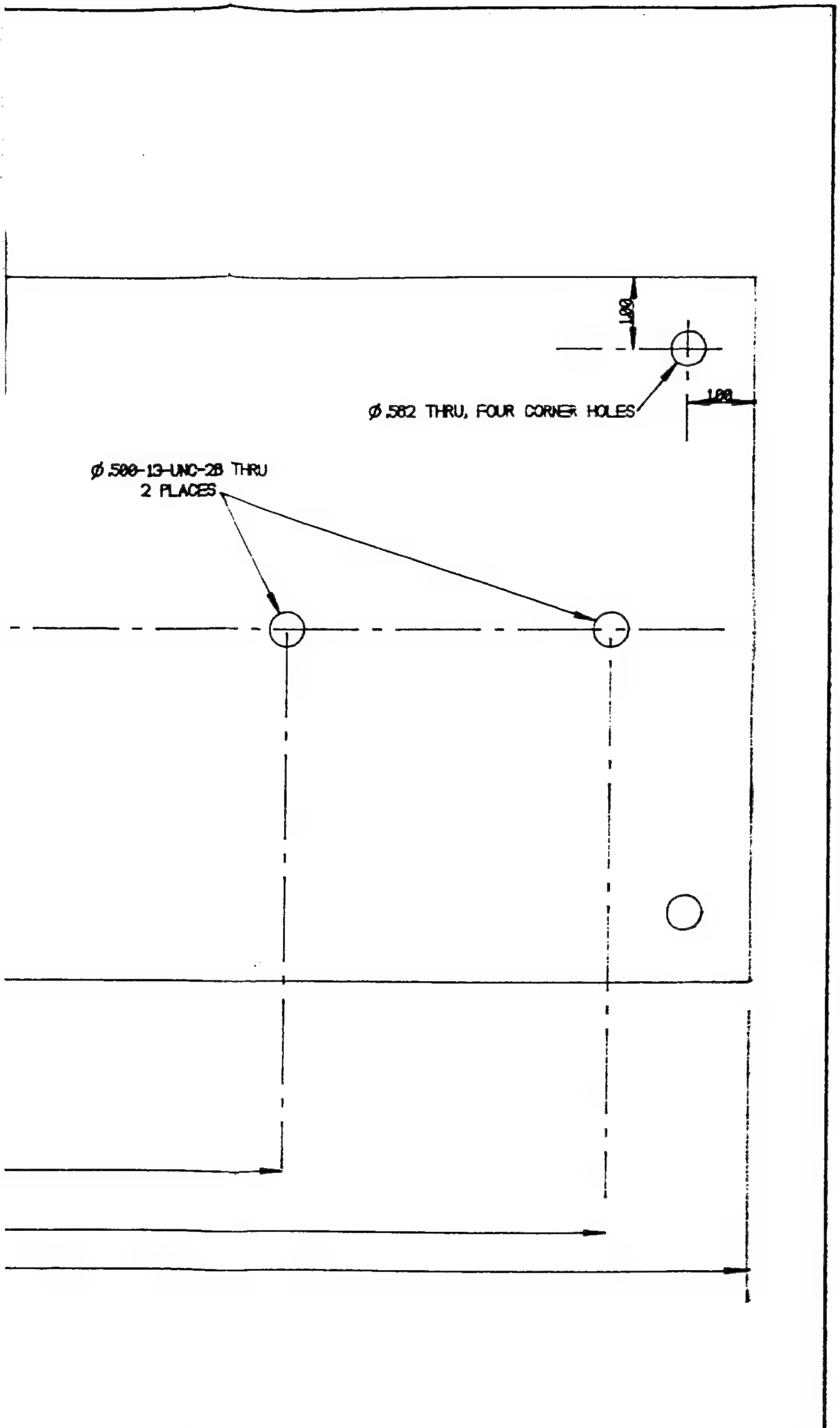
NEXT ASSY	USED ON	
APPLICATION		AC

B



		DIMENSIONSING AND TOLERANCING PER ANSI Y14.5M-1982 UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES		EDO CORPORATION ELECTRO ACOUSTIC DIVISION 2645 SALT L
		TOLERANCES: 2 PLACE DECIMAL .03		BASE PLATE
		3 PLACE DECIMAL .010	DRAWN BY R. Daley / DATE	SIZE B / CAGE 24338 / DWG NO. 678
NEXT ASSY	USED ON	INTERPRET DRAWING IN ACCORDANCE WITH DOD-D-1000	ENGINEER R. Daley	SCALE: NONE / SH
APPLICATION				

FILE: B



EDO CORPORATION
ELECTRO ACOUSTIC DIVISION
2645 SOUTH 300 WEST
SALT LAKE CITY, UTAH 84115

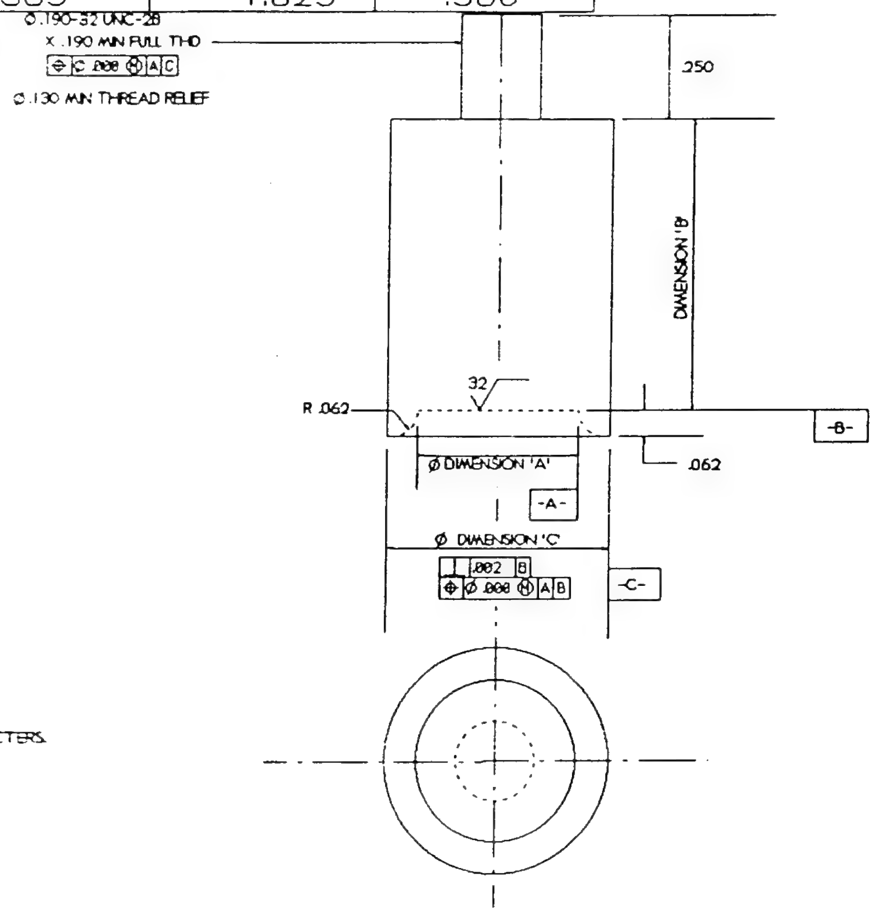
BASE PLATE

SIZE B	CAGE 24338	DWG NO. 6784RD11	REV
SCALE: NONE		SHEET 1 OF 1	

IEER
Daley

FILE: BPLATEECD

DASH NUMBERS TABLE				
DASH NO.	MATERIAL	DIMENSION 'A'	DIMENSION 'B'	DIMENSION 'C'
-1	NOTE 3	.365	.250	.530
-2	NOTE 3	.365	.500	.530
-3	NOTE 3	.365	.750	.530
-4	NOTE 3	.365	1.000	.530
-5	NOTE 4	.365	.250	.530
-6	NOTE 4	.365	.500	.530
-7	NOTE 4	.365	.750	.530
-8	NOTE 4	.365	1.000	.530
-9	NOTE 3	.365	1.25	.530
-10	NOTE 3	.365	1.375	.530
-11	NOTE 3	.365	1.500	.530
-12	NOTE 3	.365	1.625	.530



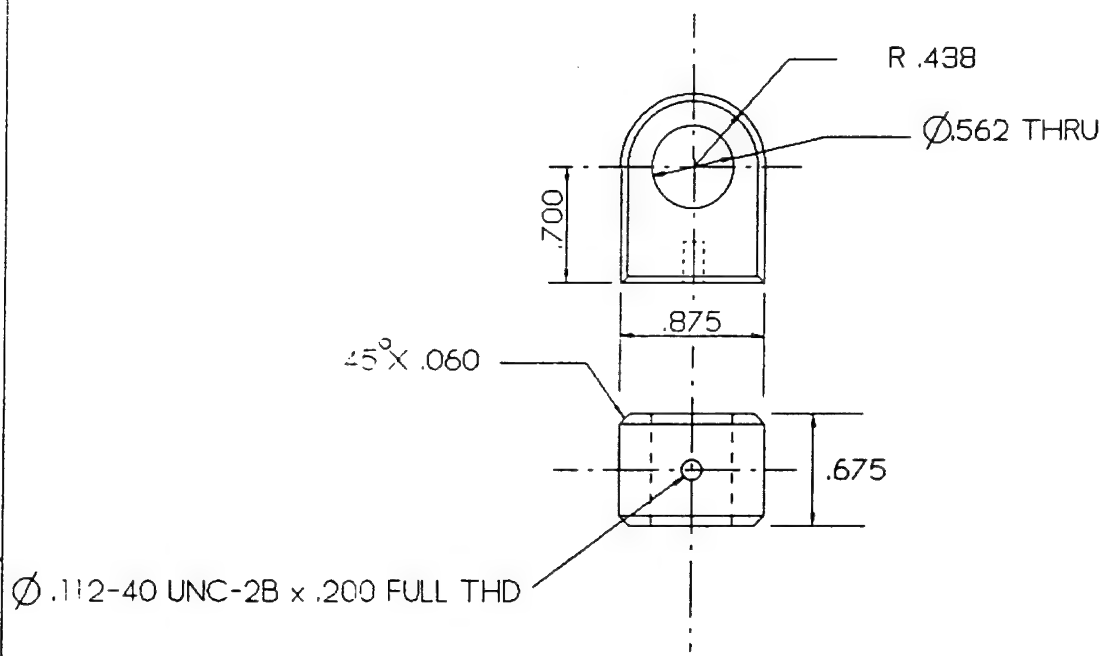
NOTES, UNLESS OTHERWISE SPECIFIED:

1. FINISH AS STOCK.
   REMOVE ALL BURRS & SHARP EDGES.
   ALL MACHINE SURFACES TO BE 125.
   UNLESS OTHERWISE NOTED
2. IDENTIFY PART BY BAG OR TAG WITH PART NUMBER AND REVISION LETTER LEGIBLY PER MIL-STD-130 USING .12 INCH HIGH CHARACTERS.
3. STAINLESS STEEL
   AISI TYPE 316 OR 316L
4. CARBON STEEL
   AISI TYPE 1006 OR 1010

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES TOLERANCES: ANGULAR ± 2 PLACE DECIMALS ± .03 3 PLACE DECIMALS ± .010	DRAWN	Rick Daley	EDO CORPORATION ELECTRO ACOUSTIC DIVISION
	CHECKED		
	STRESS	Rick Daley	DRAWING TITLE: ROD CHUCK
DO NOT SCALE THIS DRAWING	ENGRG	Rick Daley	
MATERIAL: SEE DASH NUMBER TABLE	RELEASE DATE		
	APPROVED		SIZE: A · CODE IDENT NO.: 24338 · DWG NO.: 6784RD12-☐
	SC: 87-6784-78		SCALE: NONE · REVISION: A · SHEET: 1 OF 1

FILE: RODCHUCK.FCD

APPLICATION		REVISIONS			
NEXT ASSY	USED ON	LTR	DESCRIPTION	DATE	APPROVED



NOTES, UNLESS OTHERWISE SPECIFIED:

1. FINISH AS STOCK.
   REMOVE ALL BURRS & SHARP EDGES.
   ALL MACHINE SURFACES TO BE 125
   UNLESS OTHERWISE NOTED
2. IDENTIFY PART BY BAG OR TAG WITH
   PART NUMBER AND REVISION LETTER LEGIBLY
   PER MIL-STD-130 USING .12 INCH HIGH CHARACTERS.

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES TOLERANCES: ANGULAR ± 2 PLACE DECIMALS ± .03 3 PLACE DECIMALS ± .010	DRAWN	Rick Daley	EDO CORPORATION ELECTRO ACOUSTIC DIVISION
	CHECKED		
	STRESS	Rick Daley	DRAWING TITLE:
DO NOT SCALE THIS DRAWING	ENGRG	Rick Daley	LEVER PIVOT
MATERIAL:	RELEASE DATE		
STAINLESS STEEL AISI TYPE 316 OR 316L	APPROVED		SIZE: A / CODE IDENT NO. 24338 / DWG NO. 6784RD13
	SC: 87-6784-78		SCALE: NONE / SHEET: 1 OF 1

FILE: PIVOT.FCD

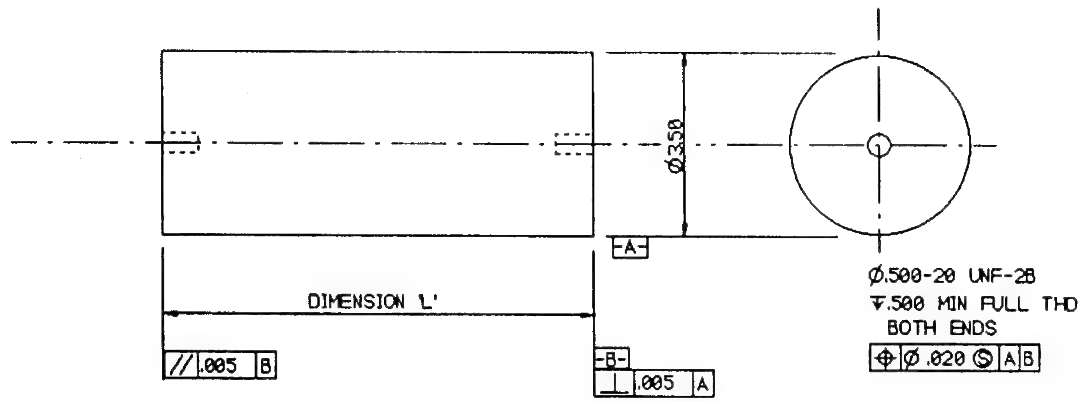
NOTES. UNLESS OTHERWISE SPECIFIED
1. FINISH AS STOCK.
REMOVE ALL BURRS AND SHARP EDGES.
ALL MACHINED SURFACES TO BE 125

2. METAL STAMP PART NUMBER AND REVISION LETTER PERMANENTLY AND LEGIBLY PER MIL-STD-130 USING .12 INCH HIGH CHARACTERS. PART NUMBER IS SAME AS DRAWING NUMBER.

3. MATERIAL: ALUM. ALLOY 6061-T6

4. FINISH: HARD ANODIZE. .002 THICKNESS. COLOR: BLACK

DASH NO.	DIMENSION 'L'
-1	6.35
-2	4.35
-3	2.35



NEXT ASSY	USED ON
APPLICATION	

DIMENSIONING AND TOLERANCING PER ANSI Y14.5M-1982
UNLESS OTHERWISE SPECIFIED
DIMENSIONS ARE IN INCHES

TOLERANCES:
2 PLACE DECIMAL ±.03
3 PLACE DECIMAL ±.010

DRAWN BY: R. Daley | DATE
ENGINEER: R. Daley

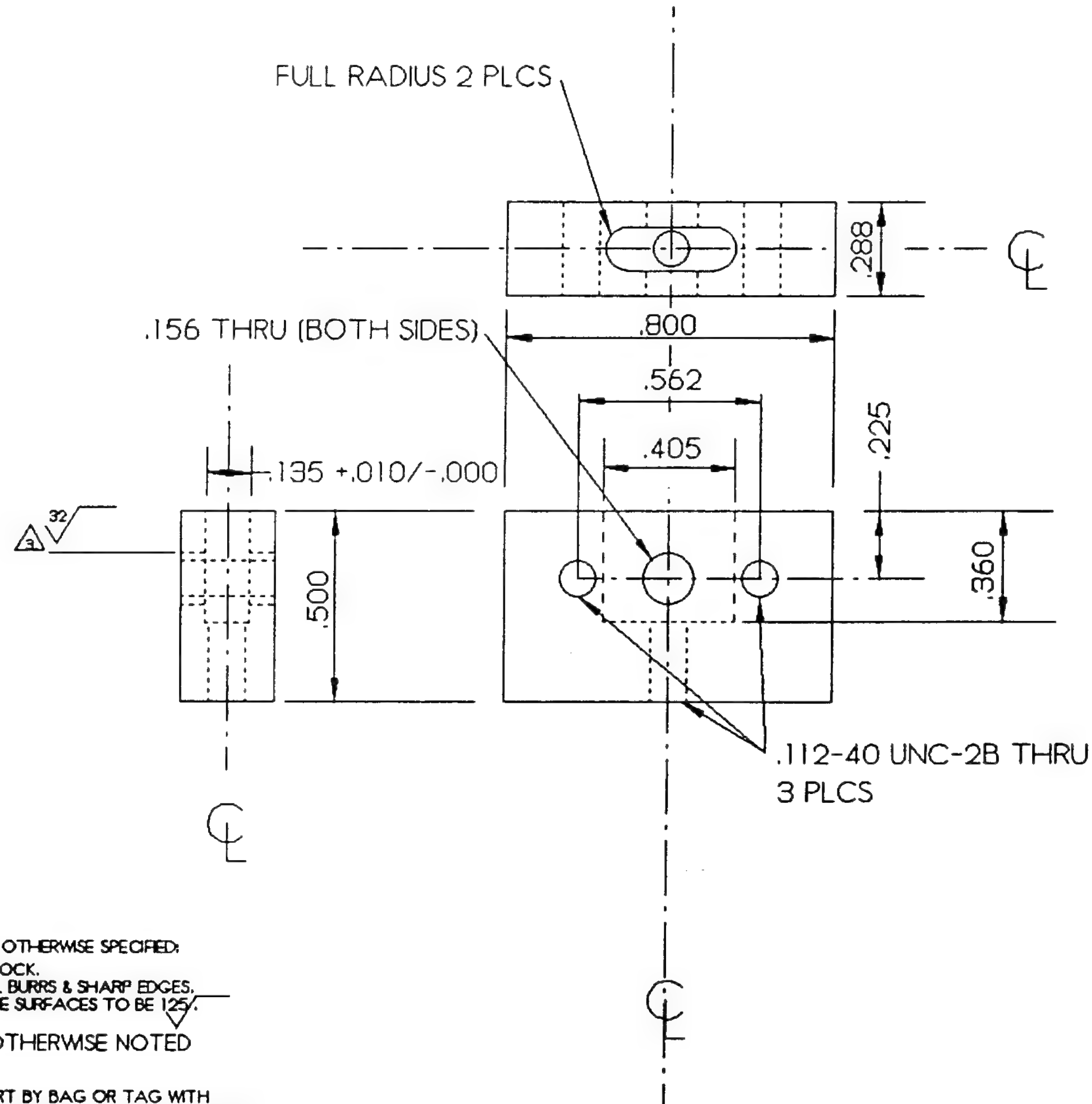
INTERPRET DRAWING IN ACCORDANCE WITH DOD-D-1000

EDO CORPORATION
ELECTRO ACOUSTIC DIVISION
2645 SOUTH 300 WEST
SALT LAKE CITY, UTAH 84115

SPACER BLOCK

SIZE	CAGE	DWG NO.	REV
B	24338	6784RD14	
SCALE NONE		SHEET 1 OF 1	

FILE: SPACERBL.FCD



NOTES, UNLESS OTHERWISE SPECIFIED:

1. FINISH AS STOCK.
   REMOVE ALL BURRS & SHARP EDGES.
   ALL MACHINE SURFACES TO BE 125.
   UNLESS OTHERWISE NOTED
2. IDENTIFY PART BY BAG OR TAG WITH
   PART NUMBER AND REVISION LETTER LEGIBLY
   PER MIL-STD-130 USING .12 INCH HIGH CHARACTERS.

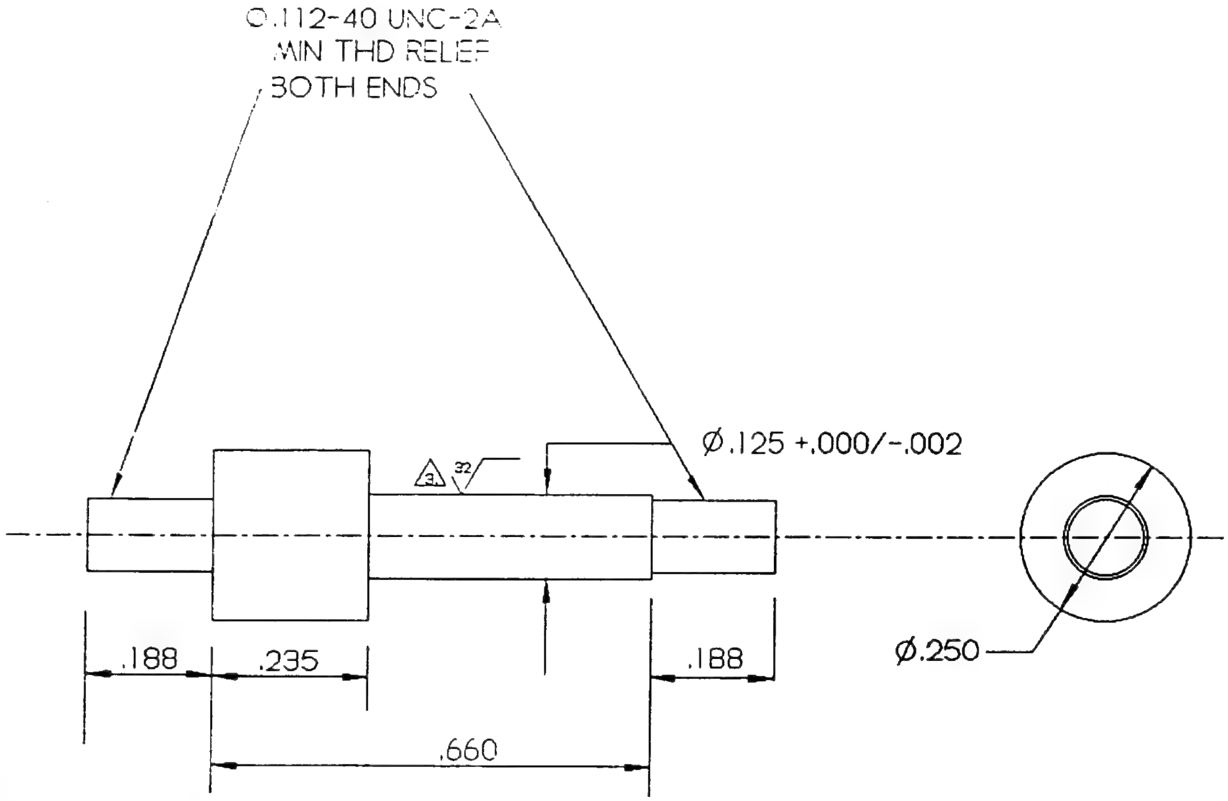
3 FINISH: AUTOCATALYTIC NICKEL/PTFE COATING, SINTERED AT 750°F
.0002 + .0001 COATING THICKNESS. DIMENSIONS APPLY AFTER COATING.

FINISH REQUIRED ON INDICATED SURFACE ONLY (.156 THRU HOLE)
OTHER SURFACES OPTIONAL

RECOMMENDED SOURCE OF COATING: LINCOLN PLATING
LINCOLN, NEBRASKA (402) 275-3671

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES TOLERANCES: ANGULAR ± 2 PLACE DECIMALS ± .03 3 PLACE DECIMALS ± .010	DRAWN	Rick Daley	EDO CORPORATION	ELECTRO ACOUSTIC DIVISION
	CHECKED			
	STRESS	Rick Daley	DRAWING TITLE:	
DO NOT SCALE THIS DRAWING	ENGRG	Rick Daley	BEARING BLOCK	
MATERIAL: STAINLESS STEEL AISI TYPE 316 OR 316L	RELEASE DATE			
	APPROVED		SIZE A / CODE IDENT NO. 24338	DWG NO. 67B4RD15
	SC: 87-6784-78		SCALE: NONE	SHEET: 1 OF 1

FILE: BEARINGB.FCD



NOTES, UNLESS OTHERWISE SPECIFIED:

1. FINISH AS STOCK.
   REMOVE ALL BURRS & SHARP EDGES.
   ALL MACHINE SURFACES TO BE 125
   UNLESS OTHERWISE NOTED
2. IDENTIFY PART BY BAG OR TAG WITH
   PART NUMBER AND REVISION LETTER LEGIBLY
   PER MIL-STD-130 USING .12 INCH HIGH CHARACTERS.
3. FINISH: AUTOCATALYTIC NICKEL/PTFE COATING, SINTERED AT 750°F
   .0002 + .0001 COATING THICKNESS. DIMENSIONS APPLY AFTER COATING.

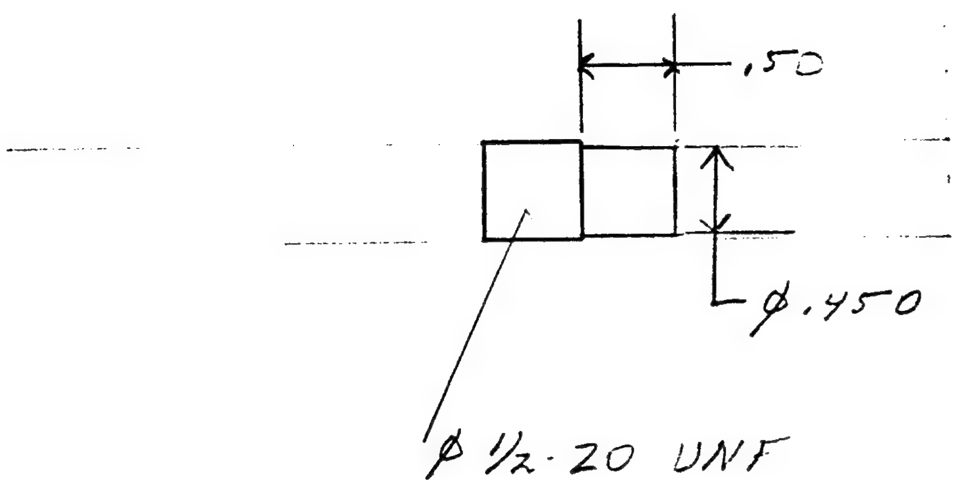
   FINISH REQUIRED ON INDICATED SURFACE ONLY (.156 THRU HOLE)
   OTHER SURFACES OPTIONAL

RECOMMENDED SOURCE OF COATING: LINCOLN PLATING
LINCOLN, NEBRASKA (402) 275-3671

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES TOLERANCES: ANGULAR ± 2 PLACE DECIMALS ± .03 3 PLACE DECIMALS ± .010	DRAWN	Rick Daley	EDO CORPORATION	ELECTRO ACOUSTIC DIVISION
	CHECKED			
	STRESS	Rick Daley	DRAWING TITLE: AXLE	
DO NOT SCALE THIS DRAWING	ENGRG	Rick Daley		
MATERIAL: STAINLESS STEEL AISI TYPE 316 OR 316L	RELEASE DATE			
	APPROVED		SIZE A / CODE IDENT NO. 24338	DWG NO. 67B4RD16
	SC: 87-6784-78		SCALE: NONE	SHEET: 1 OF 1

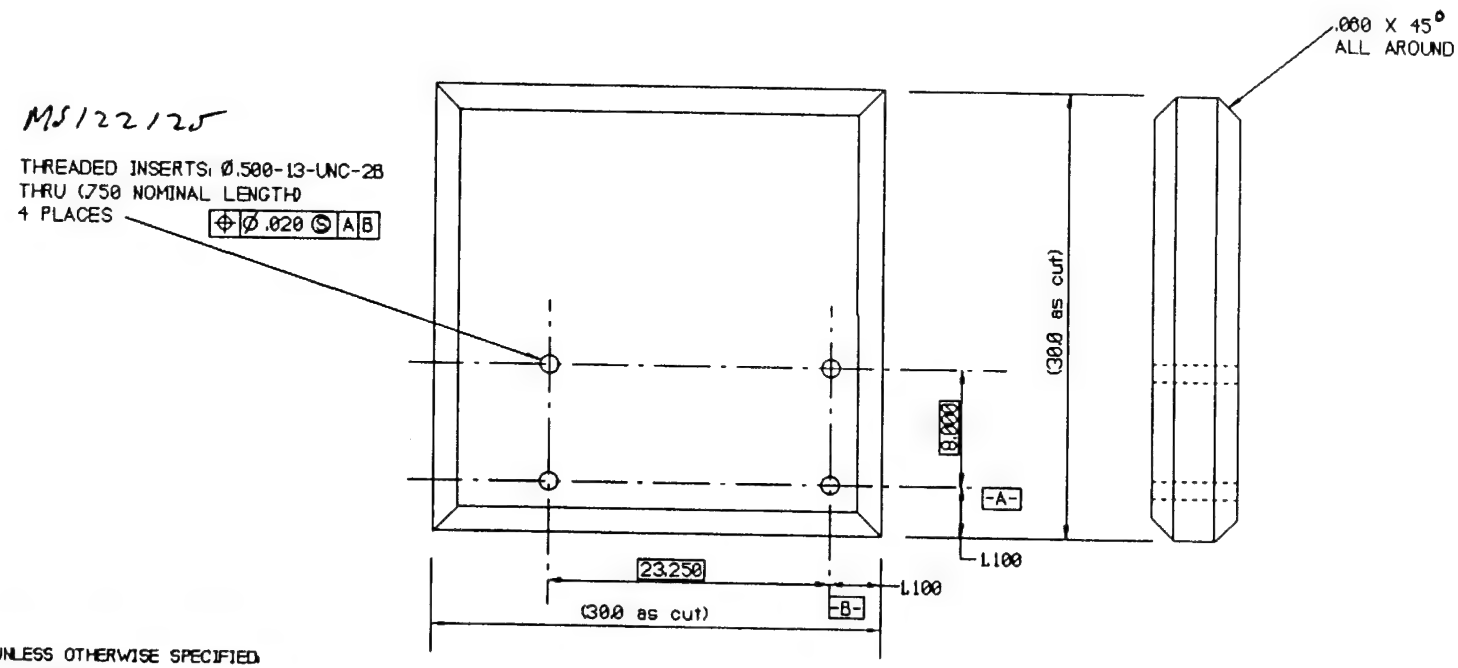
FILE: AXLE.FCD

Modify Thr



Modify Threaded Studs

DWG # 6784RD17



NOTES, UNLESS OTHERWISE SPECIFIED.

1. FINISH AS STOCK.
   REMOVE ALL BURRS AND SHARP EDGES.
   ALL MACHINED SURFACES TO BE 125 .

2. METAL STAMP PART NUMBER AND REVISION LETTER PERMANENTLY AND LEGIBLY PER MIL-STD-130 USING .12 INCH HIGH CHARACTERS. PART NUMBER IS SAME AS DRAWING NUMBER.

3. MATERIAL: ALUM. ALLOY 6061-T6. .750 THICK PLATE

4. FINISH: HARD ANODIZE, .002 THICKNESS, COLOR: BLACK

NEXT ASSY	USED ON
APPLICATION	

DIMENSIONING AND TOLERANCING PER ANSI Y14.5M-1982
UNLESS OTHERWISE SPECIFIED
DIMENSIONS ARE IN INCHES

TOLERANCES:
2 PLACE DECIMAL .03
3 PLACE DECIMAL .010

DRAWN BY R. Daley	DATE
ENGINEER R. Daley	

INTERPRET DRAWING IN ACCORDANCE WITH DOD-D-1000

EDO CORPORATION — ELECTRO ACOUSTIC DIVISION — 2645 SOUTH 300 WEST SALT LAKE CITY, UTAH 84115

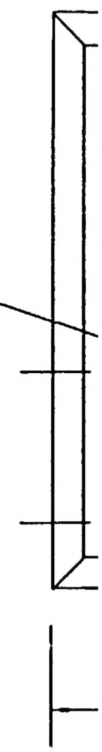
tabletop

SIZE	CAGE	DWG NO.	REV
B	24338	6784RD18	
SCALE: NONE		SHEET 1 OF 1	

FILE: tabletop.FCD

THREADED INSERTS: Ø.500-13-UNC-2B
THRU (.750 NOMINAL LENGTH)
4 PLACES

⌖	Ø.020 Ⓢ	A	B



NOTES, UNLESS OTHERWISE SPECIFIED:

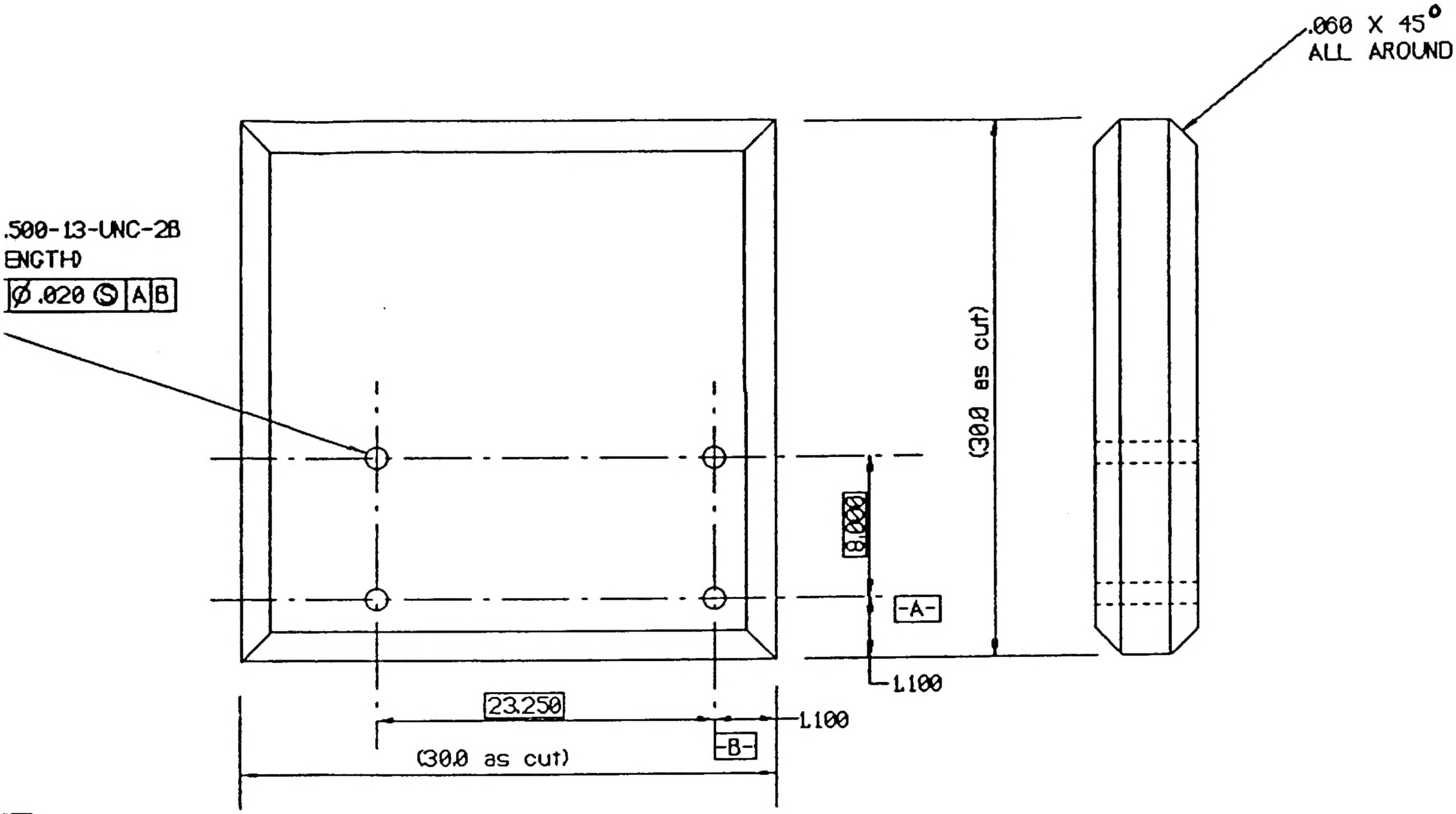
1. FINISH AS STOCK.
   REMOVE ALL BURRS AND SHARP EDGES.
   ALL MACHINED SURFACES TO BE 125 .

2. METAL STAMP PART NUMBER AND REVISION
   LETTER PERMANENTLY AND LEGIBLY PER
   MIL-STD-130 USING .12 INCH HIGH CHARACTERS.
   PART NUMBER IS SAME AS DRAWING NUMBER.

3. MATERIAL: ALUM. ALLOY 6061-T6. .750 THICK PLATE

4. FINISH: HARD ANODIZE, .002 THICKNESS, COLOR: BLACK

	B	



IED:

EDGES.
125 .

REVISION
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H CHARACTERS.
ING NUMBER.

. 750 THICK PLATE
CKNESS, COLOR: BLACK

NEXT ASSY	USED ON	
APPLICATION		

DIMENSIONSING AND TOLERANCING PER ANSI Y14.5M-1982
UNLESS OTHERWISE SPECIFIED
DIMENSIONS ARE IN INCHES

TOLERANCES:
2 PLACE DECIMAL .03
3 PLACE DECIMAL .010

DRAWN BY R. Daley | DATE

INTERPRET DRAWING IN ACCORDANCE WITH DOD-D-1000

ENGINEER R. Daley

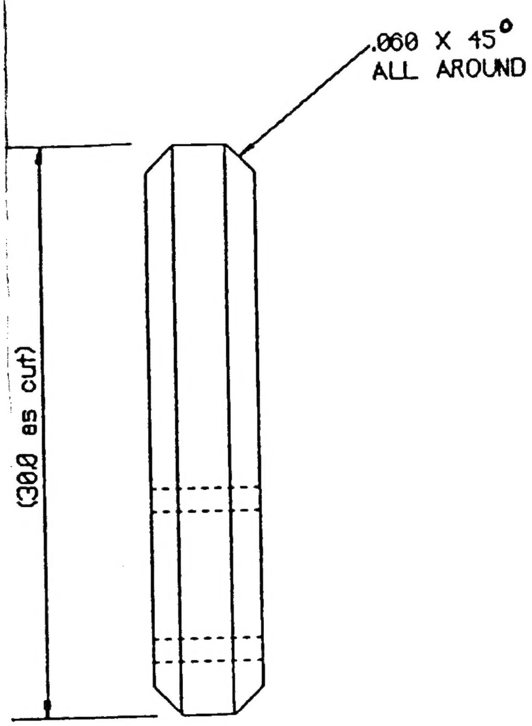
EDO CORPORATION | ELECTRO ACOUSTIC DIVISION | 2645 SOUTH 300 SALT LAKE CITY, U

tabletop

SIZE B | CAGE 24338 | DWG NO. 6784RD18

SCALE NONE | | SHEET 1 (

FILE: tabletop.



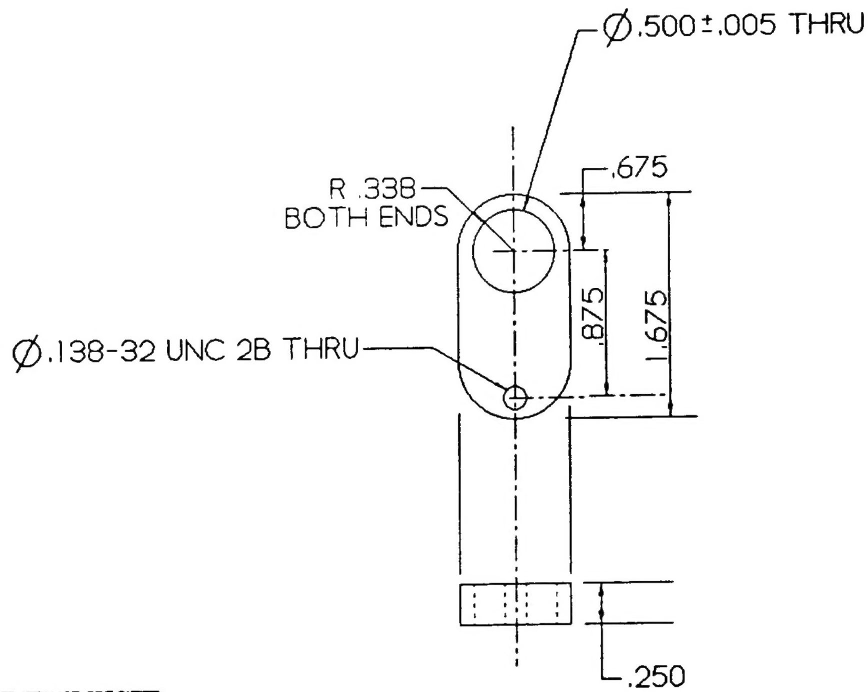
EDO CORPORATION
ELECTRO ACOUSTIC DIVISION
2645 SOUTH 300 WEST
SALT LAKE CITY, UTAH 84115

tabletop

ATE	SIZE B	CAGE 24338	DWG NO. 6784RD18	REV
GINEER Daley	SCALE NONE		SHEET 1 OF 1	

FILE: tabletop.FCD

APPLICATION		REVISIONS			
NEXT ASSY	USED ON	LTR	DESCRIPTION	DATE	APPROVED



NOTES, UNLESS OTHERWISE SPECIFIED:

1. FINISH AS STOCK.
   REMOVE ALL BURRS & SHARP EDGES.
   ALL MACHINE SURFACES TO BE 125/.
   UNLESS OTHERWISE NOTED

2. IDENTIFY PART BY BAG OR TAG WITH
   PART NUMBER AND REVISION LETTER LEGIBLY
   PER MIL-STD-130 USING .12 INCH HIGH CHARACTERS.

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES TOLERANCES: ANGULAR ± 2 PLACE DECIMALS ± .03 3 PLACE DECIMALS ± .010	DRAWN	Rick Daley	EDO CORPORATION ELECTRO ACOUSTIC DIVISION		
	CHECKED				
	STRESS	Rick Daley	DRAWING TITLE: LEVEL ADJUSTER		
DO NOT SCALE THIS DRAWING	ENGRG	Rick Daley			
MATERIAL: STAINLESS STEEL AISI TYPE 316 OR 316L	RELEASE DATE		SIZE A	CODE IDENT NO. 24338	DWG NO. 67B4RD19
	APPROVED				
	SC: 87-6784-78		SCALE: NONE		SHEET: 1 OF 1

FILE: LEVELADJ.FCD